

REPORT DOCUMENTATION PAGE					Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 05/22/2007		2. REPORT TYPE Final Technical Report		3. DATES COVERED (From - To) 11/15/2005 to 9/30/2006		
4. TITLE AND SUBTITLE Symposium Q: Magnetic Thin Films, Heterostructures, and Device Materials				5a. CONTRACT NUMBER		
				5b. GRANT NUMBER N00014-06-1-0281		
				5c. PROGRAM ELEMENT NUMBER		
				5d. PROJECT NUMBER		
6. AUTHOR(S) William Bailey, Columbia University				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Materials Research Society 506 Keystone Dr Warrendale PA 15086				8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) ONR Regional Office Chicago 230 S Dearborn Rm 380 Chicago IL 60604-1595				10. SPONSOR/MONITOR'S ACRONYM(S) ONR		
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT Distribution limitation - None						
13. SUPPLEMENTARY NOTES None						
14. ABSTRACT Attachments: Summary & Abstracts						
20070530199						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT		18. NUMBER OF PAGES	
a. REPORT	b. ABSTRACT	c. THIS PAGE	None		19a. NAME OF RESPONSIBLE PERSON Donna J. Gillespie, Symposium Fund Administrator	
N/A	N/A	N/A			19b. TELEPHONE NUMBER (Include area code) 724-779-3004 Ext 202/gillespie@mrs.org	

talks demonstrated recent developments in understanding the transport behavior (S. Franceschi, Delft Univ.) and investigations of various kinds of nanowire-based devices (L. Samuelson, Lund Univ.). The results revealed key insights on transport behavior and emphasized the critical role of interfaces and electrical contacts.

ZnO and related materials are of interest for optical and sensor applications and exhibit interesting piezoelectric properties (Z.L. Wang, Georgia Tech). A.P. Alivisatos (UC-Berkeley) demonstrated the control of complex shapes and topologies by colloidal syntheses. Detailed investigations of the photoluminescent properties and FETs based on heterostructures and core-shell structures based on ZnO were shown by G.-C. Yi (POSTECH, Pohang, Korea).

Symposium Support: First Nano Inc. and IBM Zurich GmbH.

Experimental and Theoretical Developments Demonstrated for Magnetic Thin-Film Device Materials (See MRS Proceedings Volume 941E)

In Symposium Q on Magnetic Thin Films, Heterostructures, and Device Materials, spin-dependent tunneling junctions were presented, with a particular focus on Fe/MgO/Fe junctions. Tunneling magnetoresistance values in this system have recently attained up to 350% at room temperature, several times higher than those seen in any other materials system. High magnetoresistance values were presented experimentally, treated through *ab initio* models, and correlated with MgO barrier structure by *in situ* STM and XPS characterization. Prospects for incorporation into nonvolatile magnetic RAM devices were also reviewed. Among other highlights were possibilities for novel interactions of ferromagnetic layers with other functional material types; novel rectifying possibilities, predicted theoretically, for the integration of ferroelectrics such as SrTiO₃, in the tunnel barrier between metallic Co electrodes; unambiguous proof of electrical injection and detection of spin-polarized electrons from metallic ferromagnets through GaAs, through the Hanle effect; and all-oxide magnetic tunneling junctions based on NiMn₂O₄ barriers. Materials approaches to increasing subnanosecond switching speeds, critical for high-data-rate (>1 GHz) information storage, were presented. It was shown that the damping constant for high-speed motion can be predicted from first principles only in layered structures; controlled in epitaxial Fe alloys, potentially reduced below the intrinsic value of pure Fe; correlated with the femtosecond demagnetization process; and understood microscopically through

picosecond-scale time-resolved x-ray spectroscopy. Composition spread approaches for the discovery of high-frequency magnetic materials were also reviewed.

The complex reversal process in submicrometer patterned elements could be understood using magnetic force microscopy and magnetoresistance measure-

Graduate Students Receive Gold and Silver Awards

Graduate Student Awards were announced during an evening ceremony on April 19 at the 2006 Materials Research Society Spring Meeting in San Francisco.



Gold Graduate Student Awards were awarded to (left to right) **Gengfeng Zheng** (Harvard University), **Rong Fan** (University of California, Berkeley), **Jana Zaumseil** (University of Cambridge), **Emory M. Chan** (University of California, Berkeley), and **Lane W. Martin** (University of California, Berkeley).



Silver Graduate Student Awards were awarded to (front row, left to right) **Andrea R. Tao** (University of California, Berkeley), **Christine E. Richardson** (California Institute of Technology), **Arum A. Yu** (Massachusetts Institute of Technology), **Julia Deneen** (University of Minnesota), **Rashmi Jha** (North Carolina State University), and **Lori E. Greene** (University of California, Berkeley); (back row, left to right) **Robert J. Walters** (California Institute of Technology), **Czang-Ho Lee** (University of Waterloo), **Chung-Yi Chiang** (Massachusetts Institute of Technology), **Yunseok Kim** (Korea Advanced Institute of Science and Technology), **Yongfeng Guan** (Columbia University), **Liam S.C. Pingree** (Northwestern University), and **Lidong Qin** (Northwestern University).

ments and detailed studies of hysteresis loops. Novel results were shown on multiferroic materials, in which close coupling of charge (ferroelectric) and magnetic (antiferromagnetic) ordering is predicted. Some initial evidence for the reciprocal influence of FE domains on AF domains in BiFeO_3 were presented through linear dichroism in PEEM and through hysteresis loops in YMnO_3 .

Symposium Support: ARL, ONR, and Samsung Advanced Institute of Technology.

New Trends Covered in Nanostructures and Hybrid Composites for Gas Sensors and Biomedical Applications (See *MRS Proceedings Volume 915*)

Symposium R on Nanostructured Materials and Hybrid Composites for Gas Sensors and Biomedical Applications covered new trends with bio-hybrid materials (B. Dunn, UCLA) and intercalative organic and metal oxides (I. Matsumara, AIST) and spanned over a new generation of materials, such as nanowires, both in terms of first principles (A. Kolmakov, SIUC), growth, and production (Z.L. Wang, Georgia Univ.), and their implementation to gas sensing even to the extreme of single-wire detection (J.R. Morante, Barcelona Univ.).

Among multi-parametric pattern recognition methods, colorimetric sensor arrays deserve special attention because of their capability in monitoring toxic chemicals (K. Suslick, UIUC). Very fine nanometric particles and excellent control over the dimensionality proved possible through deposition from an aerosol phase (N. Barsan, Tübingen Univ.).

Hydrogen sensing was also addressed with success through either titania nanotubes (C.A. Grimes, PSU) or a mixed tin titanium oxide solid solution (M.C. Carotta, Ferrara Univ.).

Symposium Support: Dipartimento di Fisica, Università di Ferrara.

Advances in Smart NanoTextiles Add Function to Clothing

(See *MRS Proceedings Volume 920*)

Innovations in the nanoscale manipulation of fibers and textiles have created a new momentum in designing functional garments and clothes to be used for personal mobility, healthcare, or rehabilitation. Symposium S on Smart NanoTextiles addressed new materials and fibers, sensing, and applications.

Examples of extended functionality of fibers include conducting polymer fibers (B.R. Mattes, Santa Fe Science and Technology Inc.), enhanced strain sensitivity fibers obtained by chemically polymeriz-

ing PPY (X. Tao, Hong Kong Polytechnic Univ.), and piezoelectric and ferroelectric properties by applying ultrafine vinylidene fluoride nanofibers in an electrospinning process (Y. Dzenis, Univ. of Nebraska, Lincoln). Some talks captured recent developments in shape-memory fibers, such as using triblock liquid-crystal polymers (S. Ahir, Univ. of Cambridge) or polyurethane-CNT composites.

The benefit of CNTs was also investigated by S.S. Rhahatekar (Univ. of Cambridge), who presented CNT-filled thermoplastic polymer textile fibers, and R. Baughman (Univ. of Texas, Dallas) who focused on methods for producing polymer-free CNT yarns and transparent sheets.

Inspired by nature, research groups have mimicked biological archetypes to improve the behavior of fibers. The group of Z. Guan (UC-Irvine) used the skeletal muscle protein titin as a model to develop modular multidomain polymers. C.-Y. Chiang (MIT) and colleagues examined how to incorporate the M13 bacteriophage for the design of a virus-based nanoarchitecture including nanowires.

Nanoparticle-coated fibers can enhance wearing comfort, as reported by Z. Hu (Hong Kong Polytechnic Univ.) and colleagues, who introduced a stable silver oxide suspension in chitosan that contains silver oxide nanoparticles of 10–20 nm on average. Cotton fabrics treated with this emulsion have shown significant antibacterial activity. Furthermore, in cotton, self-cleaning behavior can be improved by applying a nanocrystalline anatase titanium dioxide film from an alkoxide solution using a low-temperature sol-gel process.

In the area of inkjet printing of textiles, A. Sawhney (Univ. of Massachusetts) and colleagues reported on their printed arrays of strain sensors consisting of conducting lines and a piezoresistive polymer (PEDOT).

Approaches to Scalable, Low-Cost Nanoscale Fabrication Highlighted (See *MRS Proceedings Volume 921E*)

Symposium T on Nanomanufacturing brought together researchers from diverse areas to highlight advances being made in the formation of functional nanostructures and approaches for the patterned organization of such structures over large areas with nanoscale precision.

While manufacturing complex devices on the nanoscale is now having an impact on consumer electronic markets with the mass production of computer chips with linewidths of 65 nm, research on alternative means for nanomanufacturing offers pathways to future nanofabrication technology with smaller features and lower-cost production methods. In Symposium T, scalable capabilities for the formation of features of <65 nm and 3D fabrication were highlighted in several talks. R.S. Williams (HP) said that linewidths and spacings down to 17 nm have been obtained and integrated into a 16 Kbyte memory elements by nanoimprint lithography and that a path toward linewidths and spacings down to 4 nm is foreseeable; methods to allow defect tolerance are necessary for future-generation nanodevices. T. Makela (VTT) showed that nanoimprint lithography can be extended to roll-to-roll processes where 100-nm-wide features were pat-

Materials Research Priorities Revealed at Government Funding Seminars

The materials research community is experiencing worldwide interest in nanotechnology among other priorities from government funding agencies. Marie-Isabelle Baraton (Université de Limoges, France) discussed the priority area of nanotechnology within the European Union's 6th Framework Programme, and Hideomi Koinuma, vice president of the National Institute for Materials Science in Tsukuba, Japan, described the nanotechnology landscape in Japan, including the Nanotechnology Researchers Network Center (Nanonet). W. Lance Haworth, acting director of the Division of Materials Research at NSF, said that the nanotechnology initiative will remain a major focus for NSF but that several new programs are on the horizon, such as a biomaterials program. This program is designed to foster the study of bio-related materials and phenomena, including the investigation of biological pathways to new materials.

Harriet Kung, director of the Division of Materials Sciences and Engineering within the Office of Basic Energy Sciences at DOE, described the four solicitations planned for fiscal year 2007, including midscale instrumentation, solar energy conversion, hydrogen, and nuclear research.

In addition to the presentations on government funding, the National Academies held a Town Hall Meeting on Condensed Matter and Materials Physics (CMMP 2010) in order to get input from the MRS community of materials researchers for the next decadal study of the field of CMMP.

SYMPOSIUM Q

Magnetic Thin Films, Heterostructures, and Device Materials

April 18 - 20, 2006

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* Invited paper

8:30 AM *Q1.1

Giant Tunneling Magnetoresistance and Tunneling Spin Polarization in Magnetic Tunnel Junctions Using MgO Tunnel Barriers. Stuart Parkin, See-Hun Yang, Hyunsoo Yang, Christian Kaiser, Brian Hughes and Phil Rice; IBM Almaden Research Center, San Jose, California.

Recent advances in generating, manipulating and detecting spin-polarized electrons and electrical current make possible new classes of spin based sensor, memory and logic devices [1]. One key component of many such devices is the magnetic tunneling junction (MTJ) - a sandwich of thin layers of metallic ferromagnetic electrodes separated by a tunneling barrier, typically an oxide material only a few atoms thick. The magnitude of the tunneling current passing through the barrier can be adjusted by varying the relative magnetic orientation of the adjacent ferromagnetic layers. As a result, MTJs can be used to sense the magnitude of magnetic fields or to store information. The electronic structure of the ferromagnet together with that of the insulator determines the spin polarization of the current through an MTJ - the ratio of 'up' to 'down' spin electrons. Using conventional amorphous alumina tunnel barriers tunneling spin polarization (TSP) values of up to ~55% are found for conventional 3d ferromagnets, such as CoFe, but using highly textured crystalline MgO tunnel barriers TSP values of more than 92% can be achieved for otherwise the same ferromagnet [2]. Such TSP values rival those previously observed only with half-metallic ferromagnets. Corresponding giant values of tunneling magnetoresistance are found, exceeding 350% at room temperature and nearly 600% at 3K. Perhaps surprisingly the MgO tunnel barrier can be quite rough: its thickness depends on the local crystalline texture of the barrier, which itself is influenced by structural defects in the underlayer. The tunneling probability in an MTJ may depend on the symmetry of the electronic wave-functions which can lead to spin filtering, as theoretically predicted for Fe/MgO/Fe [3], when the symmetry of the majority and minority bands are distinct. The tunneling probability is also strongly influenced by chemical bonding at the ferromagnet/ barrier interface so accounting, for example, for little change of TSP and TMR when Co is diluted with significant amounts of Pt [4] and for high tunneling spin polarization in rare-earth transition-metal alloys with nearly zero magnetization [5]. 1 S. Parkin, X. Jiang, C. Kaiser, A. Panchula, K. Roche, and M. Samant, *Proc. IEEE* 91, 661 (2003). 2 S. S. P. Parkin, C. Kaiser, A. Panchula, P. Rice, B. Hughes, M. Samant, and S.-H. Yang, *Nature Mater.* 3, 862-867 (2004). 3 W. H. Butler, X.-G. Zhang, T. C. Schulthess, and J. M. MacLaren, *Phys. Rev. B* 63, 054416 (2001). 4 C. Kaiser, S. van Dijken, S.-H. Yang, H. Yang, and S. S. P. Parkin, *Phys. Rev. Lett.* 94, 247203 (2005). 5 C. Kaiser, A. F. Panchula, and S. S. P. Parkin, *Phys. Rev. Lett.* 95, 047202 (2005).

9:00 AM Q1.2

How Many Crystalline Interface Layers are Necessary to Create High TMR? Christian Heiliger, Peter Zahn and Ingrid Mertig; Department of Physics, Martin-Luther-University Halle-Wittenberg, Halle, Germany.

Recent experiments [1,2,3] based on epitaxially grown Fe/MgO/Fe samples shed light on the subject of tunneling magnetoresistance (TMR). First of all, the obtained TMR ratios exceed the predictions by Julliere's model [4]. Second, experimentally obtained bias voltage characteristics show features which could be related to the electronic structure of the system in the ballistic limit of tunneling. The high crystallinity of the samples [1,2,3] seemed to be the reason. New experiments [5], however, demonstrate that even amorphous electrodes attached to a crystalline MgO barrier show a TMR of more than 130%. The question that is addressed in this talk is: How many crystalline metal layers close to the interface are necessary to obtain high TMR. A screened Korringa-Kohn-Rostoker (KKR) method based on density functional theory was applied to calculate the electronic and magnetic structure of the different junctions self-consistently. The Landauer conductance of planar junctions was calculated using the Baranger-Stone scheme by means of Green's functions in the limit of coherent tunneling. [1] J. Faure-Vincent, C. Tiusan, E. Jouguet, F. Canet, M. Sajieddine, C. Bellouard, E. Popova, M. Hehn, F. Montaigne, and A. Schuhl, *Appl. Phys. Lett.* 82, 4507 (2003). [2] S. Yuasa, T. Nagahama, A. Fukushima, Y. Suzuki, and K. Ando, *Nature Materials* 3, 868 (2004). [3] S.S.P. Parkin, C. Kaiser, A. Panchula, P.M. Rice, B. Hughes, M. Samant, and S.-H. Yang, *Nature Materials* 3, 862 (2004). [4] M. Julliere, *Phys. Lett.* 54A, 225 (1975) [5] K. Tsunekawa, D. D. Djayaprawira, M. Nagai, H. Maehara, S. Yamagata, N. Watanabe, S. Yuasa, Y. Suzuki, and K. Ando, *Appl. Phys. Lett.* 87, 072503 (2005)

9:15 AM Q1.3

Finite Bias Calculations on Electronic Transport Through

Fe/MgO/Fe Tunneling Junctions. Ivan Rungger¹, Oleg Mryasov², Alexandre R. Rocha¹, Olle Heinonen² and Stefano Sanvito¹; ¹School of Physics, Trinity College Dublin, Dublin, Ireland; ²Seagate Research, Pittsburgh, Pennsylvania.

In this work we calculate the I-V characteristics of Fe/MgO/Fe(100) tunneling junctions using our recently developed code Smeagol [1]. Smeagol interfaces the non-equilibrium Green's functions (NEGF) method with density functional theory (DFT) using the numerical implementation contained in the SIESTA code [2], which is based on a linear combination of atomic orbitals basis set. Smeagol calculates self-consistently the current for a finite applied bias, and it has been tailored for simulations of magnetic materials. First we investigate the zero-bias transmission coefficients $T(E)$ as a function of the in-plane k -vector and the energy for either collinear parallel or antiparallel configurations of the magnetic leads, as well as for non-collinear orientations. Then the zero bias calculations are compared to the self-consistent calculations at finite bias, and the charging behavior of the interface is analyzed. It has been found that for small biases the minority current in the parallel configuration is mainly carried by surface states, but that it saturates for voltages above about 20 meV. In contrast, for the other spin channels of the different leads configurations the zero-bias predictions are found to be a good approximation of the self-consistent finite bias calculations. Furthermore we analyze the effect of geometrical asymmetry due to either partial asymmetric interface oxidation or due to asymmetric lattice distortions. It has been shown that these asymmetries are important for the understanding of the observed I-V curves. Finally we investigate how above results are sensitive to the inclusion of a pseudo self-interaction correction for the standard LDA exchange and correlation potential. This correction increases the bandgap of MgO compared to the LDA result, bringing it very close to the experimental value. References [1] A. R. Rocha, V. M. Garcia-Suarez, S. W. Bailey, C. J. Lambert, J. Ferrer and S. Sanvito, *cond-mat/0510083* (2005) [2] J. M. Soler, E. Artacho, J. D. Gale, A. Garcia, J. Junquera, P. Ordejon and D. Sanchez-Portal, *J. Phys.: Condens. Matter* 14, 2745 (2002)

9:30 AM *Q1.4

Tunnel Conductance Oscillation Induced by the Quantum Well in fully Epitaxial Double Barrier Magnetic Tunnel Junctions. Koichiro Inomata^{1,2}, Takayuki Nozaki¹ and Nobuki Tezuka^{1,2}; ¹Materials Science, Tohoku University, Sendai, Miyagi, Japan; ²CREST, JST, Kawaguchi, Saitama, Japan.

Quantum oscillation of the tunneling conductance was observed in fully epitaxial double barrier magnetic tunnel junctions (DMTJs) consisting of a MgO seed layer (10)/Fe (50)/MgO(2)/Fe(t)/MgO(2)/Fe(15) (the numbers are film thickness in nm), deposited on a single crystal MgO(001) substrate using the molecular beam epitaxy (MBE)[1]. The designed thickness of a middle Fe layer was varied from 1.0 nm to 1.5 nm. All layers were evaporated by electron-beam bombardment at room temperature (RT) and annealed at 300 °C for the bottom Fe electrode and 200 °C for the middle and top Fe electrodes for 20 min. in order to improve the morphology of the layer surface. The epitaxial growth of each layer was confirmed by observing the reflection high-energy electron diffraction (RHEED) patterns during deposition and after the annealing treatment. The cross-sectional transmission electron microscopy (TEM) exhibits the layered isolated islands of 10 ~ 40 nm in diameter and 5 nm in height for the middle Fe layer, which is about three times thicker than the designed thickness. We confirmed that the Fe islands grow epitaxially on the MgO barrier with very flat interface, demonstrating parallel-connected tunneling for the DMTJs. We have observed the tunnel magnetoresistance (TMR) of 110% and 135% at 5K and RT, respectively, which are comparable to that for the single magnetic tunnel junctions (SMTJs). The large TMR in the DMTJs over the value estimated by the Julliere model using the Fe spin polarization is consistent with the coherent tunneling as in the SMTJs using a MgO barrier. The conductance of the DMTJs oscillates as a function of the bias voltage in the positive bias direction for various middle Fe layer thicknesses. The bias voltage where the conductance shows maximum changes into a higher value with decreasing the middle layer thickness. We can observe the oscillatory feature even at RT for the DMTJ with $t = 1.2$ nm (actual thickness is estimated to be about 2 nm from the cross-sectional TEM analysis) in the positive bias direction, although the oscillation amplitude attenuates with increasing temperature. For the case of $t = 1.5$ nm, on the other hand, the oscillatory feature disappears at RT due to the small energy gap between the quantum levels. These characteristics demonstrate the creation of the QW states in the middle Fe layer. The conductance oscillation was observed only in the parallel magnetization configuration. This result can be explained by the QW states formed in only one of the two spin bands, because in our structure only up spin electrons of $\Delta 1$ band in the Fe(001) electrode is expected to form the QW states due to the absence of the down spin $\Delta 1$ states at the Fermi energy. Further improvement of the

quality of the quantum well layer will provides us the realization of the spin-dependent resonant tunneling effect. Reference [1] T. Nozaki, S. Nakamura, N. Tezuka and K. Inomata, Phys. Rev. Lett. submitted

10:30 AM *Q1.5

Magnetic Materials for High-Performance Toggle MRAM. Jon M Slaughter, R. W. Dave, S. V. Pietambaram, J. J. Sun, G. Grynkeiwich, M. DeHerrera, K. Smith, N. D. Rizzo and S. Tehrani; Technology Solutions Organization, Freescale Semiconductor, Inc., Chandler, Arizona.

Magnetoresistive random access memory (MRAM) employs a magnetoresistive device integrated with standard silicon-based microelectronics, resulting in a combination of qualities not found in other memory technologies. For example, MRAM is non-volatile, has unlimited read and write endurance, and has demonstrated high-speed read and write operations. Here we present an overview of the characteristics of our 4Mb Toggle-MRAM circuit based on magnetic tunnel junction (MTJ) devices, and outline paths for improving performance and scaling to higher densities. Specific technology demonstrations for improving performance and scalability of both the read and write operations will be presented. For example, high-MR, MgO-based tunnel junction material has been integrated with 180nm and 90nm CMOS circuitry to improve the read performance. The high MR values obtainable with MgO-based MTJ devices can enable significant read access time improvements, but are useful only if all the other requirements that enable fully functional MRAM circuits are met. These requirements include: narrow bit-to-bit resistance distributions, free-layer magnetic properties that produce narrow switching distributions, low interlayer coupling, good bias dependence, reliability, and thermal endurance. Results for MgO tunnel barriers grown with different processes show how the barrier structure affects the growth of the subsequently deposited magnetic material. Tests comparing properties of the 4Mb arrays with MgO-based and AlOx-based MTJ material show improved useable signal with MgO, although this polycrystalline barrier results in wider distributions for several array parameters. Paths to reduced power consumption that employ novel magnetic materials also will be presented.

11:00 AM *Q1.6

STM, XPS and Spin-Torque Studies of Magnetic Tunnel Junctions. Robert Buhrman, School of Applied and Engineering Physics, Cornell University, Ithaca, New York.

The recent advances in magnetic tunnel junction (MTJ) technology together with the demonstration of the ability of spin-polarized currents to excite and switch nanomagnets have opened up a wide range of new opportunities regarding the study and technological applications of nanomagnetism and metallic spintronics. To further advance these prospects we need new and more detailed understanding and enhanced control of these MTJ materials systems, and also of the details of spin transport through these tunnel barriers. In this presentation I will discuss results from recent STM and XPS studies in our laboratory of the chemical and electronic structure of half-formed and fully-formed magnetic tunnel junctions, which identify the nature of the electronic defects in these ultra-high oxide barrier layers and point to possible pathways for further improvement. I will also report on spin-torque experiments with MTJs which have provided a new approach to the measurement and understanding of the bias dependence of spin transport and TMR. The spin torque results demonstrate that the polarization of the tunnel current does not, at least in the systems we have studied, decrease strongly with bias, contrary to the bias behavior of the TMR. This result is quite positive for spin-torque applications of MTJs and is also consistent with the electronic structure of ultra-thin tunnel barriers as revealed by the STS and XPS studies.

11:30 AM *Q1.7

Novel Transport Phenomena in Ballistic Conductors and Tunnel Junctions. Evgeny Y. Tsymlal, Department of Physics and Astronomy, University of Nebraska-Lincoln, Lincoln, Nebraska.

In this talk we overview our recent results on modeling transport phenomena in ballistic conductors and tunnel junctions. For ferromagnetic ballistic conductors we predict that electronic transport exhibits ballistic anisotropic magnetoresistance (BAMR) - a change in the ballistic conductance with the direction of magnetization [1]. This phenomenon originates from the effect of the spin-orbit interaction on the electronic band structure which leads to a change in the number of bands crossing the Fermi energy when the magnetization direction changes. For epitaxial Co/SrTiO₃/Co magnetic tunnel junctions with bcc Co(001) electrodes we predict a very large tunneling magnetoresistance (TMR), originating from a mismatch of majority- and minority-spin states contributing to the conductance [2]. In agreement with the experimental data, we find that the spin polarization of the tunneling current across the Co/SrTiO₃ is negative. We attribute this property to the complex band structure of

SrTiO₃ which is formed from localized 3d states of Ti and, unlike MgO- and Al₂O₃-based MTJs, allows efficient tunneling of the minority d electrons of Co. Stimulated by experimental observations of ferroelectricity in thin films of a nanometer thickness, we consider a new type of tunnel barriers based on ferroelectric materials. We predict that in such *ferroelectric tunnel junctions* (FTJs) the conductance depends strongly on the direction of the electric polarization [3]. This *giant electroresistance effect* is the consequence of a different potential profile seen by transport electrons for the two opposite polarization orientations. Using a ferroelectric barrier in a magnetic tunnel junction makes it multiferroic, where ferromagnetic electrodes are separated by a ferroelectric barrier.

Multiferroic tunnel junctions (MFTJs) have the potential to provide an additional degree of freedom in controlling the conductance. We discuss possible implications following from the interplay between ferroelectric and ferromagnetic properties of the two ferroic constituents in these junctions. This work is supported by NSF and Nebraska Research Initiative. [1] J. Velev, R. Sabirianov, S. S. Jaswal, and E. Y. Tsymlal, Phys. Rev. Lett. 94, 127203 (2005). [2] J. Velev, K. D. Belashchenko, D. Stewart, M. van Schilfgaarde, S. S. Jaswal, and E. Y. Tsymlal, Phys. Rev. Lett. 95 (2005), in press. [3] M. Ye. Zhuravlev, R. F. Sabirianov, S. S. Jaswal, and E. Y. Tsymlal, Phys. Rev. Lett. 94, 246802 (2005).

SESSION Q2: Ultrafast Magnetization Dynamics and Damping Tuesday Afternoon, April 18, 2006 Room 3020 (Moscone West)

1:30 PM *Q2.1

Spin Torques and Pumping in Itinerant Ferromagnets: From Heterostructures to Bulk Dynamics. Yaroslav Tserkovnyak¹, Arne Brataas² and Gerrit E. W. Bauer³; ¹Physics Department, Harvard University, Cambridge, Massachusetts; ²Department of Physics, Norwegian University of Science and Technology, Trondheim, Norway; ³Kavli Institute of NanoScience, Delft University of Technology, Delft, Netherlands.

I will discuss a self-consistent theory of magnetic dynamics and electron transport in itinerant ferromagnets. The concepts of spin torque and spin pumping which are useful for understanding magnetization motion in isolated and current-biased heterostructures have also similar counterparts in nonuniform bulk dynamics, which can be conveniently treated using Boltzmann formalism. In particular, I will focus on the role of spin-orbit dephasing in Gilbert damping and current-driven dynamics in ferromagnetic bulk.

2:00 PM Q2.2

Modeling The Common Origin Of Fs Demagnetization And Gilbert Damping. Francesco Dalla Longa, Bert Koopmans and Wim de Jonge; Dept. of Applied Physics, Eindhoven University of Technology, Eindhoven, Netherlands.

All-optical techniques exploiting femtosecond laser pulses have opened the way towards the exploration of the ultimate limits of magnetization dynamics. It has been found that magnetic order in ferromagnetic transition metals can be quenched within a few hundred femtoseconds after laser heating. However, the microscopic interpretation of the phenomena at the sub-ps level have been a mystery until recently. In this presentation we present a microscopic model that successfully explains the ultrafast equilibration of magnetic order in ferromagnetic metals at a time scale τ_M of only a few hundred femtoseconds after pulsed laser excitation. We found that τ_M can be directly related to the so-called Gilbert damping factor α that describes damping of GHz precessional motion of the magnetization vector, thereby unifying two apparently unrelated issues in applied magnetism. The crucial ingredient in our approach is the inclusion of spin-flip processes accompanying momentum scattering with impurities or phonons. A simple model Hamiltonian is used to derive analytical expressions for both the Gilbert damping and the demagnetization. Independent of the spin-scattering mechanism, an appealingly simple equation relating the two key parameters via the Curie temperature T_C is derived, $\tau_M \sim c_0 \hbar / 2\pi k T_C \alpha$, with \hbar and k the Planck and Boltzmann constant, resp., and the prefactor $c_0 \sim 1/4$. This readily predicts a demagnetization time of ~ 100 fs for reasonable values of Gilbert damping in ferromagnetic nickel. A comparison with experiments, in which both parameters are measured on the same sample, will be discussed. Results from numerical extensions of the model, incorporating an applied magnetic field and heat diffusion out of the irradiated volume, will be presented as well. In particular, this approach allows us to simulate ultrafast laser-induced reversal of magnetization in a reverse magnetic field. Our results demonstrate that phonon-mediated spin-flip scattering is a good candidate to explain the sub-ps magnetic response. However, although the lattice is an essential ingredient, it is found that the spin

temperature is following the electron temperature (rather than the lattice temperature), and that reversal can be achieved even though the lattice temperature stays below the Curie temperature. Having established this crucial insight, a wide range of future experimental investigations can be envisioned - as presently being implemented.

2:15 PM Q2.3

Reduced Spin-lattice Coupling and Gilbert Damping in Epitaxial Fe_{1-x}V_x (50nm) Thin Films. Lili Cheng, Christian Scheck, Yong Feng Guan and William E. Bailey; APAM, Columbia University, New York, New York.

The reduction of Gilbert damping in magnetic thin films is an important materials goal for several applications in >1 GHz spin electronics, improving the signal to noise ratio (SNR) in nanoscale GMR sensors and the efficiency in spin momentum transfer (SMT) devices. Fe-low Z alloys, with average composition near $Z = 25$, are of potential interest for reduced damping due to an expected reduction in spin-lattice coupling, according to previous Einstein-de Haas experiments. We have deposited epitaxial MgO(100)/Fe_{1-x}V_x thin films by ultra high vacuum (UHV) cosputtering at a base pressure of 2×10^{-9} Torr, with Vanadium concentrations x up to 52%, spanning the $Z = 25$ composition at $x = 33\%$. The GHz relaxation rate (damping) and anisotropy constants were measured using broadband (0-40 GHz) and angle-dependent X-band (10GHz) ferromagnetic resonance (FMR). Relaxation rates were measured directly by the frequency-swept FMR linewidth Δf ; these drop from ~ 270 MHz for pure Fe to 200 MHz for Fe₆₇V₃₃ over the range of 4 to 14 GHz. 10 GHz field-swept linewidths for the pure Fe films are measured as low as $\Delta H_{pp} = 29$ Oe, close to the lowest literature measured values, indicating a minor role for inhomogeneous (extrinsic) broadening/relaxation. In angle-dependent measurements, we find a dramatic reduction in the cubic magnetocrystalline anisotropy constant K_1 up to 42% V; K_1 drops by nearly two orders of magnitude from 4.8×10^5 erg/cm³ for pure Fe to 1.5×10^4 erg/cm³ for Fe₅₈V₄₂. The concurrent reduction of relaxation rate and magnetocrystalline anisotropy is suggestive of a common origin in reduced spin-lattice coupling for the alloy.

2:30 PM Q2.4

Spin-torque Effects in Single-crystalline Fe Nanomagnets and Nanopillars. Henning Dasso^{1,2}, Ronald Lehnert^{1,2}, Daniel E. Buerger^{1,2}, Matthias Buchmeier^{1,2}, Peter A. Gruenberg^{1,2} and Claus M. Schneider^{1,2}; ¹Institut fuer Festkoerperforschung, Forschungszentrum Juelich GmbH, Juelich, Germany; ²cni - Center of Nanoelectronic Systems for Information Technology, Forschungszentrum Juelich GmbH, Juelich, Germany.

We report on measurements of current-induced magnetization switching and microwave excitations in single-crystalline Fe nanomagnets and nanopillars. We use molecular beam epitaxy to prepare single-crystalline multilayers containing three Fe layers: Fe(14)/Cr(0.9)/Fe(10)/Ag(6)/Fe(2) [thicknesses in nm]. The middle Fe layer is magnetically hardened due to antiferromagnetic interlayer exchange coupling across the Cr spacer to the 14 nm-thick Fe layer. Measurements of the magneto-optical Kerr-effect (MOKE) indicate a coupling strength of $J_1 = -1$ mJ/cm². In contrast, the topmost thin Fe layer is decoupled and, thus, acts as free layer. Nanomagnets and nanopillars with a diameter of about 150 nm are patterned by optical and e-beam lithography. The maximum observed giant magnetoresistance with the current flowing perpendicular to the layers (CPP-GMR) is 2.6% at room temperature and up to 5.6% at 4 K. Clearly different GMR curves for the magnetic field applied along easy and hard axis directions of the Fe(001) layers are due to magnetocrystalline anisotropy and, thus, proof the single-crystalline nature of the nanomagnets and nanopillars. By applying a DC current, we observe hysteretic current-induced magnetization switching at current densities larger than 2×10^7 A/cm². The critical current density and the switching behavior are different for the magnetic field applied along easy and hard axes. In nanopillars, where both the top and middle Fe layer are laterally structured to sub- μ m dimensions, current hysteresis appears for both polarities of the DC current. We assign this behavior to the switching of the top or middle Fe layer, respectively, taking into account the different spin scattering asymmetries of the Fe/Cr and Fe/Ag interfaces. High-frequency spectroscopy performed using a spectrum analyzer reveals magnetic microwave excitations in the nanomagnets. We observe a rich dependence of the excitation frequency (from 2 to 10 GHz) on the DC current, the external field strength, and in particular the field direction, again with strong differences for the field along easy and hard axes.

3:15 PM *Q2.5

Ultrafast Magnetization Dynamics, a New Frontier in X-ray Science. Andreas Scholl, Lawrence Berkeley National Laboratory, Berkeley, California.

Ultrafast magnetic writing using field and optical pulses has caught the interest of scientists because of the fascinating physics underlying the exchange of energy and angular momentum in a magnetic material and because of possible applications in data storage. Experiments in ultrafast magnetism put stringent requirements onto the experimental technique, both in terms of temporal and of spatial resolution. The availability of pulsed x-ray sources and fast detectors have now opened the door to such studies using x rays as a probe. First, I will discuss time-resolved imaging of magnetic patterns with 100 nm spatial resolution using the Photoemission Electron Microscope PEEM-2 at beamline 7.3.1.1 of the Advanced Light Source [1]. The bunch length of the storage ring sets the time resolution of 80 ps. Magnetic vortices appear in soft-magnetic micron-size structures and are characterized by a curling magnetization. We observed that the chirality or handedness of the vortex, which is determined by the out-of-plane magnetization of the nanometer-size vortex core, governed the dynamics of the structure in response to fast field pulses. The field pulses were generated by a laser-triggered Auston switch. On a faster time scale, magnetization dynamics experiments often rely on direct laser excitation of the material. Experiments using the time-resolved magneto-optical Kerr effect (TR-MOKE) [2] demonstrated the possibility of manipulating magnetism using a femtosecond laser pulse. The origin and the implications of the fsec-laser-driven demagnetization of Ni have been widely debated. X-ray magnetic dichroism is an ideal tool to probe such dynamics in complex materials because x-ray sum rules quantify spin moment, orbital moment and magnetic anisotropy of each element in a multi-element system. Furthermore, x-rays are sensitive to both ferromagnetic and antiferromagnetic order. I will present measurements of the transient spin and orbital moment of Fe/Gd following a f-sec laser excitation. The experiments were conducted using an x-ray streak camera with a temporal resolution of 2 ps at BL 4.0.2 of the Advanced Light Source. This work was supported by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 at Lawrence Berkeley National Laboratory. [1] S.B. Choe et al., Science 304, 420 (2004) [2] E. Beaurepaire et al., Phys. Rev. Lett. 76, 4250 (1996)

3:45 PM Q2.6

Measurement of Ferromagnetic Resonance (FMR) by Time-resolved XMCD: Element- and Layer-resolved Magnetization Dynamics at 2 ps and 0.1 deg. Resolution. Yongfeng Guan¹, William E. Bailey^{2,1}, Chi-Chang Kao³, Elio Vescovo³ and Dario A. Arena³; ¹Applied Physics Program, Department of Applied Physics, Columbia University, New York, New York; ²Materials Science Program, Department of Applied Physics, Columbia University, New York, New York; ³National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York.

We demonstrate an x-ray magneto-optical measurement of ferromagnetic resonance (FMR), enabling highly sensitive studies of the coupled precession of elements in an alloy and layers in a heterostructure. Small-angle (< 1.0 deg.) precession could be measured magneto-optically for the first time due to the high magnetic contrast of time-resolved x-ray magnetic circular dichroism (tr-XMCD) in the transmission geometry. Basic expectations of driven FMR precession could be verified in Ni₈₁Fe₁₉, driven to ~ 0.7 deg. cone angles at 2.3 GHz. Weak ferromagnetic coupling (~ 5 Oe), on the verge of detectability in variable-frequency FMR measurements, could be revealed clearly in the phase and amplitude of the layer-resolved in a Ni₈₁Fe₁₉(25 nm)/Cu(20 nm)/Co₉₃Zr₇(25 nm) trilayer precession. The technique enables studies of the microscopic mechanisms in relaxation / damping, either in complex materials or heterostructures.

4:00 PM Q2.7

Interface Magnetization Precession and Switching in Fe/AlGaAs (001). Gunter Luepke¹, Haibin Zhao¹, Diyar Talbayev¹, Aubrey Hanbicki², Conny Li², George Kioseoglou² and Berry Jonker²; ¹Applied Science, College of William and Mary, Williamsburg, Virginia; ²Naval Research Laboratory, Washington, District of Columbia.

Efficient spin-polarized electron injection is a prerequisite for the development of semiconductor-based spintronic devices. Several recent experimental studies have reported successful electrical spin injection from ferromagnetic metals into III-V semiconductor light emitting diodes (LEDs) using a variety of tunnel barriers. However, further improvement and optimization require a detailed understanding of interface magnetic properties. In this study, we have measured the reversal process of the Fe interface layer magnetization in Fe/AlGaAs heterostructures using magnetization-induced second harmonic generation (MSHG), and compared it with the bulk magnetization as obtained from magneto-optic Kerr effect (MOKE). The switching characteristics are distinctly different - single step switching occurs at the interface layer, while two-jump switching occurs in the bulk Fe for the magnetic field orientations employed [1]. The different switching processes lead to a deviation angle of 40-85 degrees between interface

and bulk magnetization. This behavior may result from reduced exchange interaction in the direction normal to the interface and different magnetic anisotropies at the heterojunction. To study the magnetization dynamics at the interface, we use time-resolved MSHG to investigate the coherent magnetization precession. The results are directly compared with the bulk spin precession as obtained from time-resolved MOKE [2]. At low fields, we observe a nearly opposite phase of coherent spin precession between the interface and bulk resulting from different switching processes. The field dependence of precession frequency provides a quantitative analysis of magnetic anisotropy and magnetostatic energy of the interface layer. The higher precession frequencies observed at the interface for a given applied field imply a faster magnetization switching in nanostructures where interface properties dominate, and portend higher speed operation in future nanoscale devices. [1] H.B. Zhao et al., Phys. Rev. Lett. 95, 137202 (2005). [2] H.B. Zhao et al., Appl. Phys. Lett. 86, 152512 (2005).

4:15 PM Q2.8

Field-driven Crossover in Precessional Dynamics of Lateral Ferromagnetic Heterostructures. Nikolay I. Polushkin, Steven A. Michalski, Lanping Yue and Roger D. Kirby; Physics and Astronomy, University of Nebraska-Lincoln, Lincoln, Nebraska.

Excitation spectra of mesoscopic magnetic objects are dependent of both the specific geometry of a system under study and the experimental conditions. We have discovered some unique features in the excitation spectra of periodic stripe structures composed of two different magnetic materials with magneto-optical Kerr spectroscopy. Structures were produced for two steps: (i) vacuum deposition of small portions (a few angstrom) alternatively of magnetic (Fe) and nonmagnetic (V) components up to a total film thickness of 10 nm; (ii) two-beam direct laser-interference patterning¹. Uniform laser annealing of as-deposited $\text{Fe}_{0.5}\text{V}_{0.5}$ samples causes a nearly 3-fold enhancement of their magnetization. Magnetic force microscopy imaging of the patterned structures with a periodicity of $D=3\mu\text{m}$ clearly indicates formation of regular arrays of very long magnetic stripes. In the pump-probe experiments, the spin-precession modes were excited and detected with the wave numbers of $Q < 1/D$. We demonstrate (1) the occurrence of multimode regime in spin precession and (2) the existence of a basic difference between the excitation spectra observed under parallel and transverse orientation of the external magnetic field H with respect to the stripes. There are two dominating modes (e.g., $\omega_1=10\text{ GHz}$ and $\omega_2=15\text{ GHz}$ at $H=2.2\text{ kG}$) under parallel field orientation, which yield to a single mode ($\omega_3=13\text{ GHz}$) at reorientation of H to the transverse direction. To interpret these results, we have developed a theoretical model based on Damon-Eshbach solution in the long-wavelength limit ($QD \ll 1$). The performed analysis reveals that the ω_1 and ω_2 modes can be associated with bulk band tops in homogeneous media having magnetizations M_1 and M_2 , i.e., $\omega_{1,2} = \gamma [H(H + 4\pi M_{1,2})]^{1/2}$, whereas the ω_3 mode observed under the transverse geometry is the root-mean-square of ω_1 and ω_2 . The observed crossover in the excitation spectra reflects different arrangement of the effective medium permeability tensor² under parallel and transverse orientation of the applied field. This difference results from the modification in electromagnetic boundary conditions on interfaces between the stripes. The observed multimode behavior and field-driven crossover in the lateral ferromagnetic heterostructures under study can potentially have the applications in novel microwave devices (e.g., multiband notch filters) upon the basis of Fe films having high operational frequencies in the GHz region³. Possible design of such devices is discussed. Work supported by the W. M. Keck Foundation and NSF-MRSEC. ¹N.I. Polushkin et al., J. Appl. Phys. 81, 5478 (1997). ²X.-Z. Wang and D. R. Tilley, Phys. Rev. B 50, 13472 (1994). ³R.J. Astalos, R.E. Camley, J. Appl. Phys. 83, 3744 (1998).

4:30 PM *Q2.9

Spin Dynamics in Magnetic Vortices. JooHo Park, Robert Compton, Mun Chan and Paul Crowell; Physics, University of Minnesota, Minneapolis, Minnesota.

A vortex is the simplest topological defect that can form in a magnetic system. We have used time-resolved Kerr microscopy to study vortex dynamics in ferromagnetic disks with diameters from 500 nm to 2 microns and thicknesses from 20 nm to 50 nm. In addition to ordinary spin waves, these systems show a low-frequency excitation corresponding to the translational degree of freedom of the vortex core.[1] We show how the motion of the vortex core couples to the spin wave spectrum, breaking the degeneracies that exist in the case of cylindrical symmetry.[2] I will also discuss recent work on excitations in elliptical particles, focusing on the relation between spin dynamics and inhomogeneous magnetic microstructure. This work was supported by NSF DMR 04-06029 and the NSF MRSEC program under DMR 02-12032. 1. J. P. Park, P. Eames, D. M. Engebretson, J. Berezovsky, and P. A. Crowell, Phys. Rev. B 67, 020403R (2003). 2. J. P. Park and P. A. Crowell, Phys. Rev. Lett. 95, 167201 (2005).

SESSION Q3: Poster Session: Magnetic Materials,
Mostly Metallic
Tuesday Evening, April 18, 2006
8:00 PM
Salons 8-15 (Marriott)

Q3.1

Abstract Withdrawn

Q3.2

Electrodeposition and Characterisation of Fe-Based Oxides for Magnetic Tunnel Junctions. Chien-Lung Teng and Mary P. Ryan; Department of Materials, Imperial College London, London, United Kingdom.

Magnetite (Fe_3O_4) is of interest because of fascinating magnetic properties for use in spintronic devices. In this work, polycrystalline and epitaxial Fe_3O_4 have been electrochemically deposited at low growth temperature ($<90^\circ$) upon nickel oxides formed on Single-phase rolling-assisted biaxial textured substrates (RABiTS) of pure nickel with $\{100\}<001>$ crystallographic orientation. The formation of nickel oxides is carried out by means of air-formed and surface oxidation epitaxy (SOE), respectively. XRD pattern shows there is no preferred orientation as Fe_3O_4 thin films grow on native nickel oxide; Moreover, with SOE it becomes highly out-plane and in-plane oriented due to close lattice matching between epitaxial NiO ($a=0.417\text{nm}$) and Fe_3O_4 ($a=0.840\text{nm}$). Structurally, AFM and FEGSEM images reveal Fe_3O_4 thin films are grown continuously and very flat for both cases, apart from loose clusters due to nucleation effect. These clusters agglomerate and become bigger as higher current density applied to substrates, and EDS analysis indicated stoichiometric composition of clusters is identical with Fe_3O_4 thin films. In order to form sandwich structure (FM/I/FM), here we propose Fe-based oxides, $\alpha\text{-FeOOH}$ ($N\acute{e}l$ Temperature= 400K) and $\alpha\text{-Fe}_2\text{O}_3$, as insulating/spacer layers. Magnetic properties (TMR vs. H, Resistivity vs. H and Ms vs. H) for these two magnetic tunnel junctions (MTJs) are examined.

Q3.3

Thickness and Temperature Dependent Magnetic Properties of Ultrathin Fe/Al Nanostructures. Ranjeet Brajpuria, Shilpa Tripathi, Anupam Sharma, T. Shripathi and S.M. Chaudhari; UDCSR, Indore, India.

Studies of magnetic interactions between ferromagnetic films separated by non-magnetic metallic films have been a subject of extensive investigations from both theoretical and experimental point of view. These kinds of artificial structures are expected to provide understanding of surface magnetism and transport phenomena, such as interlayer magnetic-coupling, surface anisotropy, magneto-optical effect and giant magneto-resistance, etc. In this respect, recently Fe/Al multilayer systems have been studied extensively because of their attractive soft magnetic properties such as low coercivity, high remanence and low saturation field, shown to be a good candidate for the possible above applications. Therefore, in this paper, the magnetic properties of electron beam evaporated ultra thin Fe-Al multilayers are studied as a function of Fe layer thickness keeping Al layer thickness constant. To investigate layer structure and surface morphology Grazing incidence X-ray diffraction (GIXRD) and Atomic force microscopy (AFM) techniques have been employed. Structural measurements carried out on structures having lower Fe thickness ($\leq 2\text{ nm}$) show substantial intermixing between Fe and Al layers during deposition. The resulting structures in these cases show loss of periodicity and resemble mostly a single layer composite film consisting of Fe and Al clusters. The magnetic measurement carried out using Vibrating sample magnetometer (VSM) at 300K and 100K indicates that all the multilayer samples exhibit soft magnetic properties, having in-plane easy direction of the magnetization. We have also found that coercivity increases at lower temperature for lower Fe thickness ($\leq 2\text{ nm}$) multilayer samples. The observed soft magnetic behaviour in these multilayer samples is explained in terms of a) weak magnetic interactions between crystal grains and their sizes b) morphological changes occurred due to Fe thickness variation in deposited bilayer films and c) formation of non-magnetic Fe-Al phase at the interfaces.

Q3.4

Alloy Synthesis by Atomic Layer Laminations for Read Sensor Applications. Chih-Ling Lee¹, Adrian Devasahayam², Ming Mao¹, Chih-Ching Hu², Vicent Ip² and Piero Sferlazzo²; ¹Veeco Instruments Inc, Fremont, California; ²Veeco Instruments Inc., Plainview, New York.

A novel method has been developed for synthesis of multi-element

alloys by planetary sputter deposition techniques. The alloy is formed by alternating depositions of uniform ultra-thin component layers at a fraction of a mono-atomic layer, or atomic layer lamination. A minimal layer thickness of down to 0.1 Å can be obtained such that the components can be mixed at atomic level forming a homogeneous alloy. A typical example is demonstrated here for the synthesis of Co_xFe_{1-x} alloys by alternating depositions of Co and Fe layers from pure element targets. The laminates are in the form of [Co(tCo)Å / Fe(tFe)Å]_n with a minimal individual Co (or Fe) layer thickness of 0.2 Å with a total thickness of 50 Å. The normalized magnetization as a function of Co concentration, tCo/(tCo+tFe), for the laminates with three different bilayer thickness, tCo+tFe = 1, 2 and 3 Å, along with the magnetization for the pure Co, Fe and Co₉₀Fe₁₀ alloy films. It is clear that the magnetization of the laminates matches those of the pure Co, Fe and Co₉₀Fe₁₀ alloy films. More convincingly, the compositional dependence of the laminates basically reconstructs the well-known Slater-Pauling curve of the bulk Co_xFe_{1-x} alloys. Additionally, the microstructure of the Co/Fe laminates has been investigated by XRD. The reduction of the d-spacing is followed by increasing the Co concentration until about 60% of Co. The clear microstructure transition can be observed between 60% to 80% of Co, which is due to the pure Co is fcc phase and the pure Fe is bcc phase. From these evidences, it indicates that the laminates form homogeneous alloys. The functionality of atomic layer lamination has been further demonstrated by its application in exchange biased spin-valve films for the pinned layer Co and Fe composition scan. The best pinning field is obtained with the Co₇₀Fe₃₀ pinned layer. Atomic layer lamination has proved to be a very powerful method that can be applied in thin film for fine alloy composition adjustment and synthesis of various alloys and compounds that would not be possible from conventional alloy targets.

Q3.5

How Does the Interface Structure Influence the Thickness Dependence of Tunneling Magnetoresistance?

Christian Heiliger, Peter Zahn, Bogdan Yu Yavorsky and Ingrid Mertig; Department of Physics, Martin-Luther-University Halle-Wittenberg, Halle, Germany.

New experiments [1,2,3] based on epitaxially grown Fe/MgO/Fe samples obtained TMR ratios which exceed the predictions by Julliere's model [4]. In addition an oscillating behaviour of the tunneling magnetoresistance (TMR) depending on the barrier thickness was found [1]. The measured bias voltage characteristics show features which could be related to the electronic structure of the system. The aim of our work is to demonstrate the influence of different interface geometries on the thickness dependence of the TMR ratio. One of the considered interface structures was with a mixed Fe-oxide layer on both interfaces, experimentally proven at the bottom and the top Fe electrode [5,6]. A second configuration was an ideal one, where no intermixed layer occurs, which can be produced under oxygen deficiency [2]. To complete this investigation a junction with a mixed Fe-oxide layer and an ideal interface was considered. A screened Korringa-Kohn-Rostoker (KKR) method based on density functional theory was applied to calculate the electronic and magnetic structure of the different junctions self-consistently. The Landauer conductance of planar junctions was calculated using the Baranger-Stone scheme by means of Green's functions in the limit of coherent tunneling. Positive and negative TMR ratios are obtained as a function of interface structure, independent on barrier thickness. [1] S. Yuasa, T. Nagahama, A. Fukushima, Y. Suzuki, and K. Ando, *Nature Materials* 3, 868 (2004). [2] J. Faure-Vincent, C. Tiusan, E. Jouguet, F. Canet, M. Sajieddine, C. Bellouard, E. Popova, M. Hehn, F. Montaigne, and A. Schuhl, *Appl. Phys. Lett.* 82, 4507 (2003). [3] S.S.P. Parkin, C. Kaiser, A. Panchula, P.M. Rice, B. Hughes, M. Samant, and S.-H. Yang, *Nature Materials* 3, 862 (2004). [4] M. Julliere, *Phys. Lett.* 54A, 225 (1975) [5] H. L. Meyerheim, R. Popescu, J. Kirschner, N. Jedrecy, M. Sauvage-Simkin, B. Heinrich, and R. Pinchaux, *Phys. Rev. Lett.* 87, 076102 (2001). [6] C. Tusche, H. L. Meyerheim, N. Jedrecy, G. Renaud, A. Ernst, J. Henk, P. Bruno, and J. Kirschner, *Phys. Rev. Lett.* 95, 176101 (2005)

Q3.6

Epitaxial NiFe/GaAs via Electrochemistry. Z.L. Bao¹, A.A.

Talin², A. Arrott¹ and Karen L. Kavanagh¹; ¹Physics, Simon Fraser University, Burnaby, British Columbia, Canada; ²Sandia National Laboratories, Livermore, California.

We have recently shown that α-Fe films can be grown epitaxially by electrodeposition on (111), (110) as well as (001) GaAs substrates. In this work we report the epitaxial growth of single crystalline Fe_xNi_(1-x) films by electrodeposition on n-GaAs (001) oriented substrates from aqueous electrolytes. Iron, nickel, and ammonia sulphate (FeSO₄, NiSO₄ and (NH₄)₂SO₄) electrolyte mixtures were used at room temperature, under galvanostatic conditions. The films nucleate as islands and relax the mismatch strain before coalescing into continuous layers. Pure Ni (f = 12 % when rotated about the

normal by 45°) forms (011) oriented films that are also remarkable in their purity and narrow rocking curve widths. The film compositions, as determined by energy dispersive x-ray and Auger spectroscopies, are a function of the ratio of Fe²⁺ to Ni²⁺ in the electrolyte, consistent with previous literature reports on electrodeposited films. In the presence of FeSO₄, Ni-rich Fe_xNi_(1-x), nucleates as face-centered cubic (fcc) (001) oriented films. The films remain single phase, fcc, up to an Fe composition of at least 17 at. %. With increasing additions of FeSO₄ the films nucleate in the body-centered cubic (bcc) phase forming two-phase solid solutions. For Fe concentrations above 60 at. % the films are single phase, bcc Fe-rich Fe_xNi_(1-x) films, and (001) oriented. The resulting Fe_xNi_(1-x)/GaAs interfaces are atomically abrupt exhibit close to ideal diode behaviour (barrier height 0.82 eV, n = 1.10). The strain relaxed, electrodeposited Fe films are magnetic with 2-fold and 4-fold magnetic anisotropies aligned with in-plane <100> and <110> directions. Transmission electron microscopy, SQUID, and electrical investigations of the NiFe films will be reported. ZB and KK acknowledge funding support from the BC Advanced Systems Institute and NSERC Canada. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Q3.7

Annealing Induced Changes at Co/GaAs (001) Interface.

Anupam Sharma, R. Brajpuria, Shilpa Tripathi, T. Shripathi and S.M. Chaudhari; UGC-DAE Consortium For Scientific Research, Indore, M.P., India.

In recent years, the study of magnetic thin films and their interfaces with semiconductor surface has been received considerable attention due to their potential technological applications as non-volatile memories and in the newly developing field of spintronics. In this respect, Co/GaAs system has attracted much attention of the researchers due to its applications in spintronics, Giant Magneto Resistive (GMR) devices because of the high spin polarization of the carriers at the Fermi level. However, all these properties are very susceptible to the degradation with temperature, resulting from the significant intermixing between the substrate and the overlayer. Therefore, understanding the growth and microstructural evolution of Co on GaAs substrate and how the annealing affects the structure, magnetic and electronic properties, is of great technological interest. Present study is therefore, aimed to investigate the structural, magnetic, electronic and transport properties of ion beam sputter deposited Co (40 nm) thin film on GaAs substrate followed by annealing at different temperatures. The X-ray diffraction measurements show oriented growth of as-deposited Co film in hcp (002) direction. However, the sample annealed at higher temperatures shows formation of ternary Co₂GaAs phase at the interface. The associated magnetization and resistivity measurements show decrement in magnetization and resistivity with increasing annealing temperature. Corresponding, XPS measurements also show modifications in core level as well as in valence band spectrum further supporting the formation of ternary Co₂GaAs phase at the interface. The observed results are mainly attributed to the changes in electronic structure at the Co/GaAs interface.

Q3.8

Characterization of a Continuous Flow RESS Apparatus for Growth of Magnetic Thin Films. Silvia De Dea¹, Dominic Graziani², David R. Miller¹ and Robert E. Continetti²; ¹Mechanical and Aerospace Engineering, University of California, San Diego, La Jolla, California; ²Chemistry and Biochemistry, University of California, San Diego, La Jolla, California.

A continuous flow Rapid Expansion of Supercritical Solution (RESS) apparatus has been developed to grow iron oxide thin films with particles in the range of 100nm to 1000nm. The magnetic thin film is produced by rapidly expanding a high pressure supercritical solution of ferric acetylacetonate (Fe(acac)₃) and CO₂ and directing the resulting supersonic jet onto both hot and cold silicon wafers. We have moved from a batch syringe pump type RESS source to a continuous source for better RESS/film control and better characterization of the impinging jet with a time-of-flight mass spectrometer (TOF). In the same RESS apparatus, the expansion can be made into ambient pressure conditions, passing through a shock wave, with controlled background composition, or into vacuum. While thermal decomposition of Fe(acac)₃, with subsequent formation of α-Fe₂O₃, is expected to happen only at the hot surface, we observed a weak ferromagnetic phase in the cold sample which indicates an unexpected change in the magnetic properties of the original compound, likely occurring upon interaction with the solid surface. We present SQUID, Mossbauer, and SEM magnetic and structural data for these thin particle films and discuss the energetics of the decomposition of Fe(acac)₃ on the hot and cold surfaces. We describe and characterize our continuous flow RESS apparatus, which allows us to control

particle morphology and composition by adjusting process parameters such as pre-expansion temperature, pressure and composition of the initial solution, temperature of the substrate, nozzle to substrate distance, and expansion chamber pressure and composition. We also present some combined thermodynamic, kinetic, and fluid mechanic models to describe the properties of the RESS free jet expansion and of the solubility of $\text{Fe}(\text{acac})_3$ in the jet. We discuss the details of the interface of the RESS source to the TOF mass spectrometer, designed to directly probe the RESS expansion and to help elucidate the nature of the particles that strike the surface during film growth.

Q3.9

Abstract Withdrawn

Q3.10

Magnetic Properties of Ni Nanoinclusion in Alumina.

Annika Pohl, Claudio Sangregorio and Claudia Innocenti; Dipartimento di Chimica, Università di Firenze, Sesto Fiorentino (Fi), Italy.

The preparation, characterisation and understanding of metal-ceramic nanocomposites, has received considerable attention during the past decade due to their unusual physical properties and potential applications a wide range of areas. Magnetic nano-particles dispersed in a dielectric matrix are promising for magnetic recording applications. The magnetic properties of these materials have been shown to depend on the size of the metal particles, as well as the structure. In this paper, we report the characterisation of structural and magnetical properties of nickel particles dispersed in an alumina matrix. A series of samples with different compositions, ranging from 5 to 90 atom-% Ni in $\text{AlO}_{1.5}$, was prepared by a single-step solution method. Thin films was prepared by spin-coating various substrates; Si, Al_2O_3 , Al, Pt/ $\text{TiO}_2/\text{SiO}_2/\text{Si}$, glass. The magnetic behaviour was investigated by zero field cooled (ZFC) and field cooled (FC) magnetization measurements. The structure was investigated using X-ray diffraction (XRD), scanning electron microscopy (SEM) and transmission electron microscopy with energy-dispersive X-ray spectrometry (TEM-EDS). The film thickness could be varied by changing the concentration of the solution and SEM studies showed that films up to about 100 nm could be prepared by a single deposition without cracking, while thicker films required multi-deposition. The PXRD and SAED patterns showed only weak reflections of fcc nickel metal. TEM studies showed that the films consisted of an amorphous alumina matrix, homogeneously loaded with well dispersed metal nanoparticles, the Ni particle sizes increased slightly from 4-7 nm for low Ni concentrations to 6-12 nm for samples of high concentrations.

Q3.11

Self-Assembled Growth of Ferrimagnetic Spinel Nanometric Pyramids. Florencio Sanchez¹, Nico Dix¹, Ulrike Luders², Jean Francois Bobo² and Josep Fontcuberta¹; ¹ICMAB-CSIC, Bellaterra, Spain; ²Onera, Toulouse, France.

Whereas self-assembled growth of semiconductor materials is widely investigated, the possibilities of complex oxides to grow in such a way are much less explored. However, self-assembled growth of oxides could allow functionalities not attainable with the common device fabrication technology of multilayer deposition and lateral patterning. An outstanding example is the fabrication by a self-assembly technique of arrays of ferrimagnetic spinel CoFe_2O_4 nanopillars embedded in a ferroelectric BaTiO_3 matrix [1]. The nanostructured hybrid system displayed a remarkable coupling of magnetic and ferroelectric properties not observed in ordinary multilayer structures. Understanding the growth mechanisms of these nanocomposites is essential for its controlled fabrication and optimization of properties. Here we report on the self-assembled growth of three-dimensional pyramidal objects in ferrimagnetic spinel, CoCr_2O_4 and NiFe_2O_4 , epitaxial films. The spinel islands [2] have a shape very similar to the SiGe pyramids and hut clusters, but detailed characterization reveals important dissimilarities. They are {111} faceted pyramids and hut clusters, and thus have a very high aspect ratio, and moreover, they maintain the shape during growth. The objects are perfectly oriented along the $\langle 110 \rangle$ directions and have a certain positional order along the same direction. The growth progression was investigated: at early stages strained (dislocation free) small nanometric pyramids form, which is followed by a structural relaxation and a spectacular growth of some of the objects. We demonstrate that the size of the objects (from the nanometer to the micrometer) and area coverage (from isolated pyramids to fully faceted surfaces) can be controlled by the deposition time, growth temperature and substrate used. The driving forces for the observed {111} faceted objects and surfaces, and bi-modal or single-modal size distribution are discussed. Our demonstration of self-organized growth of ferrimagnetic spinel pyramids and hut clusters of controlled size and on different surfaces may open the possibility of controlled fabrication of hybrid systems combining these ferrimagnetic structures with other functional

materials. References [1] H. Zheng et al., Science 303, 601 (2004); F. Zavaliche et al., Nano Letters 5, 1793 (2005) [2] U. Lüders et al., Phys. Rev. B, 70, 045403 (2004); Nanotechnology 16, S190 (2005)

Q3.12

Alignment-Sensitive Reversal Mechanisms of Epitaxial- FeF_2 /Polycrystalline-Ni Exchange Biased Thin Films. Justin Olamit¹, Kai Liu¹, Zhi-Pan Li² and Ivan K. Schuller²;

¹Physics Department, University of California, Davis, California; ²Physics Department, University of California - San Diego, La Jolla, California.

Magnetization reversal mechanisms of epitaxial- FeF_2 /polycrystalline-Ni exchange biased thin films have been investigated with vector magnetometry on a Vibrating Sample Magnetometer (VSM). The samples have been exchange biased by field cooling along the FeF_2 spin axis, the [001] direction. The transverse hysteresis loops - sensitive to magnetic moments perpendicular to the applied field - show that when the applied field is misaligned with the FeF_2 spin axis, the reversal is predominantly by rotation [1, 2]. When the applied field is aligned with the spin axis, the transverse loop is flat, indicating predominantly domain formation and motion. We have employed a First Order Reversal Curve (FORC) [3, 4] technique to further investigate the reversal mechanisms. When the applied field is aligned with the spin axis, FORC analysis shows that the magnetization switching is highly irreversible (82%), indicating that domain nucleation and motion is likely the reversal mechanism. With a misalignment of 5° , the FORC shows that majority of the magnetic switching (57%) was by a reversible mechanism, consistent with the rotation seen with vector magnetometry. These results show that the magnetization reversal mechanisms are extremely sensitive to the alignment of the applied field with the antiferromagnet spin axis and the exchange bias direction. *Work supported by ACS-PRF, Alfred P. Sloan Foundation, and DOE. 1. Olamit, Arenholz, Li, Petravic, Roshchkin, Morales, Batlle, Schuller, and Liu, Phys. Rev. B 72, 012408 (2005). 2. Olamit, Li, Schuller, and Liu, Phys. Rev. B, in press. 3. Davies, Hellwig, Fullerton, Denbeaux, Kortright and Liu, Phys. Rev. B 70, 224434 (2004). 4. Davies, Hellwig, Fullerton, Jiang, Bader, Zimanyi, and Liu, Appl. Phys. Lett. 86, 262503 (2005).

Q3.13

Computational and Experimental Evidences for Asymmetric Interfacial Mixing of Co-Al system. Sang-Pil Kim^{1,2}, Jae-Young Park³, Kwang-Ryeol Lee¹, Chung-Nam Whang³ and Yong-Chae Chung²; ¹Future Technology Research Division, Korea Institute of Science and Technology, Seoul, South Korea; ²CPRC, Department of Ceramic Engineering, Hanyang University, Seoul, South Korea; ³Institute of Physics & Applied Physics, Yonsei University, Seoul, South Korea.

For the development of thin film multiplayer devices such as MRAM or GMR/TMR sensors, atomic scale intermixing at the interface should be controlled in a systematic manner. In the present work, we employed classical molecular dynamics simulation to investigate the atomic scale intermixing at room temperature during thin film deposition in Co-Al binary system. When Co atom was deposited on Al(001) surface, atomic intermixing was easily achieved at the interface, and highly ordered CoAl compound phase of B2 structure was formed spontaneously. On the other hand, when Al atom was deposited on Co surface, atomically sharp interface was formed between the deposited Al layer and Co substrate. Using a coaxial impact collision ion scattering spectroscopy (CAICISS) and a magneto-optical Kerr effect (MOKE) measurement, these asymmetric intermixing phenomena were confirmed. Experimentally observed interfacial structures were in good agreement with the simulation results.

Q3.14

Quadrupole Magnetic Force Microscopy Tip and its Imaging Performance. Gang Han^{2,1}, Yihong Wu² and Yuankai Zheng¹;

¹Data storage Institute, Singapore, Singapore; ²Electrical and Computer Engineering, National University of Singapore, Singapore, Singapore.

Magnetic force microscopy (MFM) has become a standard tool for investigating magnetic nanostructures by detecting the magnetic stray field distribution of a magnetic sample. The research on MFM has been centered on several aspects which include but are not limited to resolution enhancement, stabilization improvement, quantitative image interpretation and tip-sample interaction reduction. So far, many efforts had been made to improve the resolution of MFM through sharpening the tips using different approaches such as attaching carbon nanotubes to the original tips, trimming the tips by focus ion beam, electron beam lithography, and ion beam etching, selective deposition by self-field emission, electron beam irradiation,

and focused electron beam decomposition and deposition. We have previously demonstrated that the resolution of the MFM tips can be further improved by using an FM/Ru/FM trilayer as the magnetic coating. The improvement was attributed to the formation of a point-dipole tip because of the antiferromagnetic coupling between the two FM layers, which form a relative smaller effective volume interacting with the sample than that of the single layer tip. In order to further improve the performance of the tip, in this work we reported on the fabrication and testing of a double synthetic tip in which a central thicker FM layer is antiferromagnetically coupled with two thinner FM layers at both sides via an ultrathin Ru layer. The tip was prepared by coating one side of a bare tip with a structure of Ta (10nm) / NiFe (2nm) / IrMn (10 nm) / CoFe (4nm) / Ru (0.8nm) / CoFe (10nm) / Ru (0.8nm) / CoFe (4nm) / IrMn (10nm) / Ta (10nm). In this design, it is expected that a quadrupole will be formed at the apex of the tip from the two synthetic structures. Theoretically this kind of tip should have a better resolution because the dipoles due to the two synthetic layers are oriented opposite with each other, leading to a reduction of DC response of the overall tip. Our preliminary results showed that the performance of the tip is comparable to that of the conventional tips. Further experiments are being carried out to optimize the structure of the tips so as to improve its performance.

SESSION Q4: Switching of Devices and Heterostructures
Wednesday Morning, April 19, 2006
Room 3020 (Moscone West)

8:30 AM *Q4.1

Switching Issues for High Density MRAM. Taewon Kim¹, Keewon Kim¹, Youngjin Cho², Injun Hwang², Jangeun Lee⁴ and Wonchul Jeong³, ¹Nano Devices Lab., Samsung Advanced Institute of Technology, Suwon, South Korea; ²Nano Fabrication Center, Samsung Advanced Institute of Technology, Suwon, South Korea; ³Advanced Technology Development Team, Semiconductor R&D Division, Suwon, South Korea; ⁴Process Development Team, Semiconductor R&D Division, Suwon, South Korea.

Successful demonstrations by the previous studies ensure that MRAM technology is a strong candidate of universal memory among the other new memory technologies from the viewpoints of power consumption, speed, scalability, retention, endurance, and density. However there are still some fundamental issues to be solved to realize density requirement that is attributed to small switching margin in the core array consisting of sub-micron or deep submicron magnetic tunnel junction (MTJ) cells[1]. In a MRAM array, the conventional writing operation uses a half selection scheme that induces a magnetic field simultaneously by two orthogonal line currents on a specific cell. However some cells selected by only one current line, Digit line (D/L) or Bit line (B/L), are partially or fully switched, which cells acts as a fail bit in the array. This writing scheme is directly related to the low writing current margin due to asteroid distribution. In this study, we consider the technological issues to improve the writing margin in submicron MRAM array, such as low Ms free layer, Synthetic anti-ferromagnetic (SAF) free layer and ultra-smooth roughness of bottom electrode. A new switching architecture without digit line current, which uses a local magnetic field generated directly by the current flowing at bottom electrode, is also proposed. I. Taewon Kim, et al, J. of Magnetism. and Magnetic. Materials. 282, 232-236 (2004)

9:00 AM *Q4.2

Giant Magnetoresistance in Multilayer Magnetic Rings. Caroline A. Ross, F.J. Castano, D. Morecroft and W. Jung; Materials Science and Engineering, MIT, Cambridge, Massachusetts.

Thin film magnetic multilayer rings exhibit a variety of interesting magnetic states and have applications in memory, logic or sensing devices. We have prepared circular and elliptical rings with diameters of 500 nm - 20 μ m from pseudo-spin-valve Co/Cu/NiFe films and spin-valve IrMn/Co/Cu/NiFe films. Each ring has 4 - 6 non-magnetic electrical contacts, and has been characterised by magnetoresistance measurements. Major loops show three well-defined resistance states corresponding to the NiFe and Co in parallel onion states (lowest resistance), the NiFe in an onion and the Co in a vortex state (intermediate resistance) and the NiFe and Co in antiparallel onion states (highest resistance). The range of stability of these configurations depends on the ring geometry and ellipticity and on the layer thicknesses. Minor loops, in which the NiFe is cycled without disturbing the Co, were also measured. The NiFe behavior differs depending on whether the Co is in a vortex state, in which case it weakly interacts with the NiFe, or whether the Co is in an onion state, in which case there are strong magnetostatic interactions between the layers. The details of reversal, for example the chirality of the vortex state in the Co, and the propagation of domains in the NiFe, can be deduced from these measurements. Moreover,

measurements using more than one contact geometry enable the behavior of specific segments of the rings to be followed. This rich behavior makes the rings suitable for multiple-bit storage, and possibly for programmable logic devices.

9:30 AM Q4.3

Control of Vortex Chirality in Magnetic Ring Elements*. Vitali Metlushko¹, P. Vavassori², M. Grimsditch³, U. Welp³, N. Zaluzec³, G. Crabtree³, J. Unguris⁴, B. Illic⁵, A. Imre⁶, L. Ji⁶, W. Porod⁶ and Xiaobin Zhu⁷; ¹UIC, Chicago, Illinois; ²University of Ferrara, Ferrara, Italy; ³MSD ANL, Argonne, Illinois; ⁴NIST, Gaithersburg, Maryland; ⁵Cornell University, Ithaca, New York; ⁶University of Notre Dame, Notre Dame, Indiana; ⁷University of Alberta, Edmonton, Alberta, Canada.

Recent studies on Co, Ni and permalloy rings have shown that a totally flux-closed magnetic vortex structure is stable at remanence. The two chiralities of the vortex, clock-wise and anti-clock-wise, have been proposed as the carriers for the stored information that could be read in a magneto-resistance-based device. To visualize the magnetization reversal process in individual rings we employed several different imaging techniques: magnetic force microscopy (MFM), scanning Hall microscopy, magneto-optical (MO) imaging, Lorentz STEM (LSTEM) and scanning electron microscopy with polarization analysis (SEMPA). We found that MO, LSTEM and SEMPA allow a direct determination of magnetic vortex chiralities and that by controlling the shape of the nanoscale magnetic ring and the direction of applied magnetic field we can precisely tune the switching mechanism and reliably predict the chirality of the vortex states. The experimental results were compared with detailed micromagnetic simulations. *Supported by the US NSF under contract DMR-0210519. Work at ANL was supported by US Department of Energy, BES Materials Sciences under contract W-31-109-ENG-38.

9:45 AM Q4.4

Domain Structures and Current-controlled Switching Characteristics of Micron Sized Permalloy Structures with Varying Aspect Ratios. S. C. Seah, Y. S. Soh and V. Ng; Information Storage Materials Laboratory, Electrical and Computer Engineering Department, National University of Singapore, Singapore, Singapore.

In this paper, we shall explore the different domain configurations observed during the switching process of micron sized permalloy structures with aspect ratios of 2, 3 and 4 as well as their current-controlled switching characteristics. The shape is a rectangle with a semicircle attached at each end. Permalloy 40nm thick round-ended rectangles of size 4μ m x 1μ m and 2μ m x 1μ m were fabricated in an array using electron beam lithography and deposited using thermal evaporation. The array was placed on a 50μ m wide 200nm thick gold conductor fabricated using photolithography and thermal evaporation. Using magnetic force microscopy, we examined the remnant states of the 4μ m structures after attempting to switch the domain configuration of the structures with the magnetic field generated by passing a current through the conductors. The current value was varied to determine the switching current of the structures. Equivalent field strength was calculated using Finite Element Method Magnetics (FEMM) simulation of the 50nm gold conductor. MFM images were used to observe the remnant state of saturation state as well as the remnant states of the intermediate fields of the switching process in both the easy and hard axis. M-H loops of the structures were obtained using the vibrating sample magnetometer. At the same time, using Object Oriented Micro-magnetic Framework (OOMMF), we simulated the M-H loops and the images of the domain configurations from -1T to 1T. We relaxed the various states observed at different fields to determine the switching field required. The MFM images as well as the M-H loops were compared with simulation results. The MFM images of the 4μ m x 1μ m structures showed a quasi-single domain configuration when saturated along the easy axis. Switching along the hard axis was unstable and the array showed different states even after attempted saturation at high current of 1A. From the simulations, the quasi-single domain was observed in the easy axis switching, confirming the MFM images. The 3-diamond state was dominant when saturated along the hard axis while 2-diamonds and multi-diamond states were also observed. The as-deposited images of 2μ m x 1μ m structures showed dominantly single-diamond domain configurations and some displaying chess-board configurations. OOMMF simulations showed that easy axis saturation resulted in 1-diamond structure when relaxed after applying a low field and chess-board structure after a high field application. Hard axis saturation resulted in single-vortex structure at low field, triangle structure at intermediate fields and 1-diamond structure at high fields. We will report on these sizes as well as the 3μ m x 1μ m structures to complete the characterization of different aspect ratios for this shape.

10:30 AM *Q4.5

Fingerprinting Magnetization Reversal in Magnetic

Nanostructures. Kai Liu, Physics Department, University of California, Davis, California.

Magnetization reversal is often complex and difficult to quantify, yet critical for the understanding and applications of magnetic nanostructures. Here we present recent studies using a first order reversal curve (FORC) method [1-5] on a few technologically important systems. In Co/Pt multilayers [3], we have found three distinct regions as the reversal domains nucleate, propagate, and finally are annihilated. Interestingly, the FORC diagram exhibits significant irreversible switching for applied fields that are well beyond the apparent saturation field, and thus provides a direct measure of the true saturation field. Transmission x-ray microscopy reveals that some residual bubble domains still persist beyond the apparent saturation and significantly alter the subsequent magnetization reversal. In exchange spring magnets [4], we have investigated the effect of the hard layer crystallinity on irreversible switching by FORC and vector magnetometry. In Fe/epitaxial-SmCo films, the reversal proceeds by a reversible rotation of the Fe soft layer, followed by an irreversible switching of the SmCo hard layer. In FeNi/polycrystalline-FePt films, the FeNi and FePt layers reverse in a continuous process via a vertical spiral. The successive vs. continuous rotation of the soft/hard layer system is primarily due to the different hard layer anisotropy. In arrays of Fe nanodots [6], we have studied a single-domain to vortex state transition as the nanodot diameter increases. Striking differences in the FORC diagrams have been observed. The 52nm nanodots exhibit single domain behavior and the resultant FORC distribution is a narrow ridge along the local coercivity axis with zero bias. The 58 and 67nm nanodots exhibit vortex states. Their magnetization reversal displays clear stages of reversible and irreversible behavior. The corresponding nucleation and annihilation fields and their distributions have been quantitatively captured. Finally, we have used the FORC method to probe magnetization reversal and nanoscopic magnetic-phase separation in $\text{La}_{1-x}\text{Sr}_x\text{CoO}_3$ [5]. These results demonstrate that FORC is a powerful method for magnetization reversal studies, due to its extreme sensitivity to irreversible switching and the capability of quantitatively mapping out distributions of magnetic properties within a system. *Work done in collaboration with J. E. Davies, R. K. Dumas, O. Hellwig, E. E. Fullerton, J. S. Jiang, S. D. Bader, H. G. Katzgraber, C. P. Pike, G. T. Zimanyi, R. T. Scalettar, K. L. Verosub, G. Denbeaux, J. B. Kortright, J. Wu, C. Leighton, I. V. Roshchin, C. P. Li, and I. K. Schuller, supported by NSF, ACS-PRF, DOE, UC-CLE, and the Alfred P. Sloan Foundation. [1] Pike, et al, JAP, 85, 6660 (1999). [2] Katzgraber, et al, PRL 89, 257202 (2002). [3] Davies, et al, PRB 70, 224434 (2004). [4] Davies, et al, APL 86, 262503 (2005). [5] Davies, et al, PRB 72, 134419 (2005). [6] Liu, et al, APL 81, 4434 (2002).

11:00 AM Q4.6

Onset of Exchange Anisotropy in Tetragonal Distorted fcc-Cobalt(001)/ γ -Manganese(001) Bilayers. Harm Wieldraaijer, Wim J.M. de Jonge and Juergen T Kohlhepp; Applied Physics, Eindhoven University of Technology, Eindhoven, Netherlands.

We use well-prepared ultrathin fct-Co(001) films as templates for the stabilization of tetragonal distorted γ -Mn(001) films by Molecular Beam Epitaxy (MBE) methods. The Mn overlayers can be grown with a very high crystalline quality and extremely flat in a layer-by-layer mode up to a thickness of roughly 20-25 monolayers (ML). Above this thickness, the Mn films slightly roughen but still keep their face-centered-tetragonal (fct) structure, until above roughly 60 ML a transformation to the complex body-centered-cubic α -Mn bulk structure occurs. X-ray Photoelectron Spectroscopy (XPS), Auger Electron Spectroscopy (AES), as well as Auger/Photoelectron Diffraction (AED/XPD) measurements show that extensive interdiffusion and/or CoMn alloy formation at the Co/Mn interface can be excluded. With a combination of LEED, AED/XPD, and X-ray Diffraction (XRD) results, the tetragonal distortion of the Mn films is determined to $c/a = 1.06$. Recent ab-initio calculations predict an in-plane (001) antiferromagnetic (AFM) state for such a c-axis expanded γ -Mn phase. Indeed, room temperature (RT) antiferromagnetism of the fct-Mn is evidenced by the observation of a shifted magnetization loop and an enhanced coercive field for fct-Mn covered ferromagnetic (FM) Co(001) buffer layers, which is explained by a unidirectional exchange anisotropy induced by an exchange interaction at the FM-Co/AFM-Mn interface. Temperature dependent magnetization measurements for samples with $>20\text{ML}$ Mn indicate blocking temperatures around 400 K and Néel temperatures well above 450 K. A closer MOKE investigation of the thickness dependence of the coercivity (HC) and the shift field (HE) as a function of the Mn thickness using wedge shaped sample structures, shows two interesting features: (1) An enhanced HC is observed for Mn thicknesses as small as 1.3 ML (at 10 K) and 3 ML (RT), respectively, clearly evidencing the AFM state in ultrathin Mn films. (2) At 10 K a small negative HE is already observed at a thickness lower than 2 ML Mn, keeping its negative sign for thicker films,

whereas at RT a small positive HE first sets in around 3-4 ML Mn, which is thereupon changing at 5-6 ML Mn into a negative HE. This change of sign in HE is also observed as a function of temperature for Mn-thicknesses between 2 and 5 ML. In the course of the presentation, this striking behaviour will be explained by the interplay of the growth mode of the Mn on the Co(001)-buffer layer and the thickness dependent magnetic properties of the ultrathin Mn overlayers.

11:15 AM Q4.7

Planar Domain Walls in Exchange Biased Bilayers. Elke Arenholz, Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, California.

Hysteresis loop shifts away from zero field to negative or positive field values, asymmetrical magnetization reversal processes for descending and ascending fields, and increased coercivity are only a few of the changes that are observed in the hysteresis loop of a ferromagnetic thin film grown on an antiferromagnetic layer after field cooling the system through the Neel temperature of the antiferromagnet. To describe the changes induced by the field cooling or exchange biasing a number of models have been proposed emphasizing the role of planar domain walls in the ferromagnetic [1] and antiferromagnetic [2] layer. Combining soft x ray magnetic circular and linear dichroism measurements allows us to monitor the magnetic order in the ferromagnetic and antiferromagnetic layers, respectively, and to test the applicability of these models to a variety of systems: + Monitoring the magnetization reversal in a thin Co layer inserted at different depth in a Fe layer grown on FeF_2 allows us to determine a depth profile of the magnetization reversal the ferromagnetic layer. We observe that the angle between bias direction and magnetization vector - obtained by measuring the magnetization component parallel and perpendicular to the applied field - is reduced near the Fe/ FeF_2 interface as compared to the surface of the ferromagnetic Fe layer. This suggests the formation of a partial parallel domain wall in the Fe layer. + Scholl *et al.* [3] presented evidence for the formation of an antiferromagnetic exchange spring in a NiO single crystal exchange coupled to a Co thin film using magnetic linear dichroism. In a similar experiment on Co/ MnF_2 and Ni/ FeF_2 bilayers, we observe a very small magnetic linear dichroism at the Mn L_3 edge indicating the rotation of the Mn spins upon magnetization reversal in the Co layer. However, no indication for the formation of an antiferromagnetic domain wall in FeF_2 was found. We attribute and will discuss this difference in behaviour in terms of anisotropy fields of the antiferromagnetic layer (14.9 T in FeF_2 and 0.7 T in MnF_2). The Advanced Light Source is supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. [1] M. Kiwi, J. Mejia-Lopez, R.D. Portugal, and R. Ramirez, Appl. Phys. Lett. 75, 3995 (1999). [2] D. Mauri, H.C. Siegmann, P.S. Bagus, and E. Kay, J. Appl. Phys. 62, 3047 (1987). [3] A. Scholl, M. Liberati, E. Arenholz, H. Ohldag, and J. Stöhr, Phys. Rev. Lett. 92, 247201 (2004).

11:30 AM Q4.8

Controlling Magnetism by Stacking Individual Atomic Monolayers of Magnetic- and Non-magnetic Materials. Farid El Gabaly¹, Silvia Gallego², Christof Klein⁴, Carmen Munoz², Laszlo Szunyogh^{3,6}, Peter Weinberger³, Kevin F. McCarty⁵, Andreas K. Schmid⁶ and Juan de la Figuera⁴; ¹Dpt. de Física de la Materia Condensada and Centro de Microanálisis de Materiales, Universidad Autónoma de Madrid, Madrid, Madrid, Spain; ²Instituto de Ciencia de Materiales de Madrid, Madrid, Madrid, Spain; ³Center for Computational Materials Science, Technische Universität Wien, Vienna, Austria; ⁴Sandia National Laboratories, Livermore, California; ⁵Lawrence Berkeley National Laboratory, Berkeley, California; ⁶Budapest University of Technology and Economics, Budapest, Hungary.

Magnetic properties of films are often a function of film thickness; for quite some time this has been a fruitful topic for research as well as for device applications. In this work we show just how rich these phenomena are, when measurements are made using microscopes that allow us to study essentially defect-free film regions in which thickness is perfectly homogeneous on the atomic scale coupled to fully relativistic ab-initio calculations. Spin-polarized low-energy electron microscopy (SPLEEM) simultaneously shows the detailed atomic-layer structure of ultrathin films during their deposition and provides with a detailed picture of magnetic properties. When we deposit films of Co onto Ru(0001) substrates in the thickness range of up to 3 atomic monolayers, SPLEEM reveals that the easy axis of magnetization switches twice in this range: both one-monolayer and three-monolayer thick regions are magnetized in a direction within the film plane, while two-monolayer thick Co/Ru(0001) regions are magnetized perpendicular to the film plane. By measuring the thickness-dependent relaxation of epitaxial strain in the Co layers and combining the experimental information with ab-initio computations of the magnetic anisotropy energy, we show how the unusual layer-by-layer double-spin-reorientation transition results can be

understood in detail. Moreover, we find rather curious, additional possibilities to induce dramatic changes of the magnetism by adding atomic monolayers of Cu on top of the Co films. When we add just one single atomic Cu layer on top of in-plane magnetized Co/Ru(0001) films of three or four monolayer thickness, the magnetization axis switches to the direction perpendicular to the film plane. Adding just one additional Cu atomic layer flips the magnetization again to an in-plane configuration. Fully relativistic ab-initio calculations show that these spin reorientation transitions are the result of effects at the Cu/Co interface.

SESSION Q5: Novel Materials: High Frequency and Spin Injection
Wednesday Afternoon, April 19, 2006
Room 3020 (Moscone West)

1:30 PM *Q5.1

Magnetostrictive Materials for High Frequency Applications. R. Bruce van Dover¹, Noble C. Woo² and Jonathan R. Petrie¹;

¹Materials Science and Engineering, Cornell University, Ithaca, New York; ²Chemistry and Chemical Biology, Cornell University, Ithaca, New York.

The magnetostrictive properties of thin films at high frequencies (~ 100 MHz - 1 GHz) are of interest for a variety of applications, such as Magnetostrictively Transduced Surface Acoustic Wave Devices (MTSAWs) and strain-assisted switching in magnetic memory devices. We have studied MTSAW devices and demonstrated their feasibility, albeit with a high insertion loss due to incorporation of a magnetic layer with only a low magnetostriction. In order to improve performance we have employed various approaches to obtaining a larger magnetostrictive response. One approach involves engineering the Ferromagnetic Resonance (FMR) frequency of the magnetic material to coincide with an acoustic resonance, which leads to increased overall magnetoacoustic coupling at that resonance frequency. Experimental observation confirms the expected effect, although the response is complex. A second approach is to identify materials with a high response, $d\lambda/dH$, where $\lambda(H)$ is the field-dependent magnetostriction. In order to evaluate the magnetostriction of a wide range of materials in an efficient manner, we prepare composition-spread films using a three-gun on-axis magnetron cosputtering system. Measurement of λ in uniform-composition thin films has typically been accomplished by measurement of (overall) substrate curvature as a function of field. We have developed a method to measure λ locally by depositing the composition-spread films on prefabricated 2D arrays (75×75) of small (typically $50 \times 500 \mu m$) cantilever beams prepared on a silicon substrate using MEMS techniques. A magnetic field is applied in two directions using orthogonal Helmholtz coils. The magnetostriction of the film results in differential strain of the thin film/cantilever system, and the resulting curvature is detected using an optical system and automated x-y scanning. The data are then analyzed to yield a quantitative measure of the quasistatic magnetostrictive response, $\lambda(H)$, at each position. This combinatorial materials science study directly identifies promising thin film compositions, but the data must be interpreted with care, since incident-angle effects can lead to anomalous magnetic anisotropy in the films. In the past, the development of magnetostrictive materials has focused on development of bulk materials with high λ (thin film work has focused on finding materials with low λ) so this approach represents a novel strategy with unique potential.

2:00 PM *Q5.2

Spin Waves and Dynamic Coupling in 2-D Magnetic Nanowire Arrays. M. H. Kuok¹, Z. K. Wang¹, H. S. Lim¹, S. C. Ng¹, J. L. Goh¹, H. L. Su² and S. L. Tang²; ¹Department of Physics, National University of Singapore, Singapore, Singapore; ²National Laboratory of Solid State Microstructure, Nanjing University, Nanjing, Jiangsu, China.

There is increasing interest in patterned magnetic nanostructures such as arrays of dots, stripes and wires because of their potential applications in magnetic memory and sensing devices [1]. Spin wave confinement effects arising from the low dimensionality of these structures are also of great interest to fundamental science [2, 3]. However, little is known about the collective spin wave modes arising from the interaction between the nanomagnet elements. A theory of this interaction, due only to dipolar coupling in an array of ferromagnetic nanowires, has recently been formulated by Arias and Mills [4]. A recent study has been carried out on collective spin wave modes in permalloy nanowire arrays, but the observation of these modes in these samples is not conclusive [5]. The interaction for these samples is weak as permalloy is a relatively soft magnetic material and the inter-wire separations were too wide (105 nm). In this abstract, we report on a Brillouin light scattering study of collective spin wave modes in ordered arrays of 20 nm-diameter FeCo nanowires

with periodic inter-wire spacings ranging from 30 to 60 nm. FeCo was chosen as it has a high saturation magnetization. Samples were fabricated by filling FeCo into porous alumina templates made from 2-step electrochemical anodization process [6]. Brillouin measurements were carried out in the backscattering geometry, with the magnetic field applied parallel to the nanowire axis. One magnon of the arrays is observed in the p-s polarized spectra, and its frequency is found to be proportional to the applied magnetic field. At a constant magnetic field, the magnon frequency is found to increase with separation of the wires and approach that of the single wire when the wire separation is wider than 50 nm. These results agree very well with the predictions of the Arias and Mills theory. The interaction between the nanowires is expected to have significant effects on the spin dynamics of magnetic nanowires in densely packed arrays. This study clearly shows the effects of such dynamical coupling in 2-D magnetic FeCo nanowire arrays. [1] H. Zheng, et. al., Science 303, 661 (2004). [2] S. O. Demokritov, B. Hillebrands, and A. N. Slavin, Phys. Rep. 348, 441 (2001). [3] Z. K. Wang, H. S. Lim, H. Y. Liu, S. C. Ng, M. H. Kuok, L. L. Tay, D. J. Lockwood, M. G. Cottam, K. L. Hobbs, P. R. Larson, J. C. Keay, G. D. Lian, and M. B. Johnson, J. Appl. Phys. 98, 046103 (2005). [4] R. Arias and D. L. Mills, Phys. Rev. B. 67, 094423 (2003). [5] H. Y. Liu, Z. K. Wang, H. S. Lim, S. C. Ng, M. H. Kuok, D. J. Lockwood, M. G. Cottam, K. Nielsch, and U. Gosele, J. Appl. Phys. 98, 046103 (2005). [6] H. L. Su, G. B. Ji, S. L. Tang, Z. Li, B. X. Gu, and Y. W. Du, Nanotechnology 16 429 (2005).

2:30 PM *Q5.3

Combinatorial Investigation of Magnetic Metallic Alloy Thin Films. Ichiro Takeuchi, ¹Materials Science and Engineering, University of Maryland, College Park, Maryland; ²Center for Superconductivity Research, University of Maryland, College Park, Maryland.

We have developed a methodology for rapidly investigating large compositional phase space of magnetic metallic alloy thin films and heterostructures in order to optimize their properties for a variety of magnetic device applications. A number of deposition techniques have been implemented for synthesis of combinatorial thin film libraries of different designs. High vacuum three-gun magnetron co-sputtering systems are used to create composition spreads on 3-inch Si wafers, where natural compositional gradient across the wafers can cover large fractions of ternary phase diagrams. Wavelength dispersive spectroscopy is used to map the exact composition distribution of every wafer. A newly developed multi-gun combinatorial electron-beam deposition system has an automated 2-dimensional shutter system which allows fabrication of libraries with well-defined compositional variation across $1 \text{ cm} \times 1 \text{ cm}$ chips. In order to quickly survey the composition-structure-magnetic property relationship across combinatorial samples and identify possible new compositions with enhanced physical properties, various rapid characterization techniques are employed together. Room-temperature scanning SQUID microscopy allows magnetic mapping of the magnetic field distribution. Obtained distribution is converted to quantitative remanent magnetization mapping using a numerical algorithm. Synchrotron x-ray magnetic circular dichroism and magneto-optical Kerr effect have been used to systematically measure hysteresis loops at different sites. Scanning x-ray microdiffraction is performed to map the structural phase distribution. I will discuss experiments where we used the co-sputtering technique to study ternary systems containing Heusler alloys and related compounds for screening of ferromagnetic shape memory alloys, magnetostrictive materials, and spintronic materials. Investigation of exchange coupling between hard and soft magnetic layers aimed at optimizing nanocomposite permanent magnets in bilayer libraries made by the electron-beam deposition system will also be discussed. This work is performed in collaboration with M. Wuttig, S. E. Lofland, F. C. Wellstood, L. Knauss, J. W. Freeland, M. Yu and J. P. Liu. This work is supported by ONR, NSF and DARPA.

3:30 PM *Q5.4

Ferromagnetic Metal/Compound Semiconductor Heterostructures: Growth, Interfacial Reactions and Spin Transport. C. J. Palmstrom¹, C. Adelman¹, X. Lou², X. Y. Dong¹, B. D. Schultz¹, J. L. Hilton¹, J. Q. Xie¹, J. Strand², S. A. Crooker³, M. Furi⁴, D. L. Smith⁴ and P. A. Crowell²; ¹Dept. of Chemical Eng. & Mat'l Science, University of Minnesota, Minneapolis, Minnesota; ²School of Physics & Astronomy, University of Minnesota, Minneapolis, Minnesota; ³National High Magnetic Field Laboratory, Los Alamos National Laboratory, Los Alamos, New Mexico; ⁴Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

Control of the interfacial properties of ferromagnetic metals and semiconductors is important for optimizing magnetic properties and spin dependent transport across these interfaces. Interfacial reaction studies have been used to determine metal-Ga-As thin film phase diagrams and for predicting the thermodynamic stability of

ferromagnetic metallic compounds on GaAs. Molecular beam epitaxial (MBE) growth in combination with in-situ STM, XPS, Auger, RHEED and LEED and ex-situ XRD, RBS, TEM, magnetotransport and magnetic characterization have been used to develop ferromagnetic elemental and metallic compound/compound semiconductor tunneling contacts for spin injection. These have included epitaxial Fe, Fe₃Ga, Co₂MnGe, and δ -MnGa ferromagnetic contacts on Ga_{1-x}Al_xAs. The efficiency of the spin polarized current injected from the ferromagnetic contact was determined by measuring the electroluminescence polarization of the light emitted from Al_{1-x}Ga_xAs light emitting diodes. Interfacial reactions and the semiconductor device band structure were found to have a dramatic influence on the measured spin injection. Lateral spin-transport devices with epitaxial Fe source and drain tunnel-barrier contacts were fabricated. Kerr microscopy was used to image the electrical spin injection and accumulation in the n-doped GaAs channel. The emission of spins from the source was observed, and a region of spin accumulation was imaged near the ferromagnetic drain contact. Both injected and accumulated spins have the same orientation (antiparallel to the contact magnetization), indicating that electron spins are polarized by reflection from the ferromagnetic drain contact. The electrical conductance could be modulated by controlling the spin orientation of optically injected electrons flowing through the drain contact.

4:00 PM *Q5.5

Current-induced Macrospin vs. Spin-wave Excitations in Spin Valves. Arne Brataas¹, Yaroslav Tserkovnyak² and Gerrit E. W. Bauer³; ¹Department of Physics, Norwegian University of Science and Technology, Trondheim, Norway; ²Physics Department, Harvard University, Cambridge, Massachusetts; ³Kavli Institute of NanoScience, Delft University of Technology, Delft, Netherlands.

We will discuss current-induced magnetic excitations in spin valves. We have found that the spin transfer torque exerted on the magnetization by transverse spin currents as well as the Gilbert damping constant depend strongly on the wave length of the excitation (spin wave). The onset of macrospin (zero wavelength) vs. finite wavelength spin-wave instabilities depends on the device parameters and the current direction, in agreement with recent experimental findings.

4:30 PM Q5.6

Properties of Epitaxial Films of the Heusler Alloy Co₂Cr_{1-x}Fe_xAl. Rajesh Kelekar and Bruce Clemens; Stanford University, Stanford, California.

We have grown epitaxial thin films of the Heusler alloy Co₂Cr_{1-x}Fe_xAl. Compounds with small x – the level of Fe doping – have been predicted to be half-metallic, where the conduction electrons at low temperature all have the same spin. In addition, bulk polycrystalline compacts of Co₂Cr_{0.6}Fe_{0.4}Al displayed negative magnetoresistances of ~30% at room temperature in magnetic fields of less than 1000 Oe. The properties of the single crystalline thin films we have grown for the first time show a sharp dependence on the level of Fe doping. Films with low Fe doping show large semiconductor-like resistivities, large reductions in the magnetic moment as compared to theory, and large values of the anomalous Hall resistivity. X-ray magnetic circular dichroism of these thin films shows that the magnetic moment on the Cr atom is virtually extinguished. Anomalous x-ray diffraction indicates that the films across the whole range of compositions contain a significant amount of selective transition metal disorder, where the transition metal atoms are disordered on the lattice sites while the Al atom is positioned on a single lattice site. These features indicate that Cr is much more sensitive to the local environment than is Fe. We have incorporated these Heusler alloys into epitaxial superlattices with Cr and spin valve-type trilayers. Though superlattices do not show giant magnetoresistances or any evidence of antiferromagnetic coupling, current-in-plane spin valves show large giant magnetoresistances of up to 7% at room temperature, the largest for any Heusler alloy or proposed half-metal.

4:45 PM Q5.7

CrSb/GaSb Heterojunction - a Possible Robust Spin Current Injector. Yuan Ping Feng, Rongqin Wu, Guowen Peng and Lei Liu; Physics, National University of Singapore, Singapore, Singapore.

Recent experiment on spin current injected from half-metal (Co₂MnGe) to semiconductor (GaAs) shows a much lower polarization than what is anticipated. Loss of half-metallicity and spin-flip due to interface atomic inter-mixing and discontinuity are possible causes for the low polarization. Thus, it is important to carefully examine structures of half-metal and semiconductor interfaces and investigate their effects on polarization of spin current in order to achieve efficient spin injection. Band alignment at the

half-metal and semiconductor interface also plays an important role. When the Fermi level of the conducting spin is shifted up towards or over the conduction band minimum of the semi-conducting spin, severe spin-flipping may occur. Here, based on ab initio calculations, we propose half-metallic CrSb as an ideal spin current source when interfaced with GaSb. Half-metallicity can be maintained at the CrSb/GaSb interface. The spin-flip gap remains sufficiently high even under the bias needed to inject the conducting spin to n-GaSb.

SESSION Q6: Magnetic Nanoparticles and Nanowires
Thursday Morning, April 20, 2006
Room 3020 (Moscone West)

8:30 AM Q6.1

Submicron Spherical Hollow Magnets: Synthesis, Dispersibility, Coercivity and Glassiness. Kunio Awaga¹, Yasuharu Kozuka¹, Mototaka Ohnishi¹, Hirofumi Yoshikawa¹, Shunji Bandow², Sumio Iijima², Motoyasu Kobayashi³ and Atsushi Takahara³; ¹Nagoya University, Nagoya, Japan; ²Meijo University, Nagoya, Japan; ³Kyushu University, Fukuoka, Japan.

The preparation of sub-micron magnetic hollow spheres is a promising approach towards developing novel magnetic materials. Their comparatively large size means that the critical temperatures of magnetic ordering or magnetization blocking would be high enough for practical application. In addition, the spherical hollow structure is advantageous for various surface modifications, which would enable further applications. Further, the magnetic domains that exist on the hollow sphere are of great interest to fundamental science; various domain patterns are energetically allowed in this highly-symmetric shape, in contrast to a needle-shape magnet, which always exhibits magnetic polarization parallel to the needle axis. The existence of these energetically-degenerated domain structures should lead to materials that change their magnetic property under certain conditions. In the present work, we prepared spherical hollow magnets of ccp- and hcp-Co, Co₃O₄, Fe, Fe₃O₄, α -Fe₂O₃, etc. with a diameter of ca. 500 nm and a shell thickness of ca. 50 nm, using polystyrene-bead templates. These particles were characterized by SEM, TEM, ED, XRD, etc. The magnetic measurements on the Fe₃O₄ particles revealed a temperature-dependent coercive field that showed a significant decrease with an increase in temperature in the wide range 2-300 K. By a surface modification with hydrophilic organic polymers, the Fe₃O₄ spheres obtained good dispersibility in water. The separate syntheses of hollow spheres of ccp- and hcp-Co were successful under nearly identical calcination conditions, but from different precursors.

8:45 AM Q6.2

Low-temperature Synthesis, Assembly, and Properties, of Monodisperse FePt-silica core-shell Nanomagnets of Tunable Size, Composition and Thermal Stability. Qingyu Yan¹, Arup Purkayastha¹, Taegyun Kim¹, Roland Kroger², Arijit Bose³, Theodorian Theodorian Borca-Tasciuc⁴ and Ganapathiraman Ramanath¹; ¹Materials Science, Rensselaer Polytechnic Institute, Troy, New York; ²Institut für Festkörperphysik, Universität Bremen, Otto-Hahn-Allee, Bremen, Germany; ³Chemical Engineering Department, University of Rhode Island, Kingston, Rhode Island; ⁴Mechanical Engineering Department, Rensselaer Polytechnic Institute, Troy, New York.

We demonstrate low-temperature (30 °C) synthesis of FePt nanoparticles with simultaneous control over size, dispersity, composition and thermal stability using water nanodroplets stabilized by non-ionic surfactants (e.g., Brij 56) in iso-octane. The nanoparticle structure, morphology and chemistry are measured by a combination of X-ray and electron diffraction, transmission electron microscopy, energy dispersive X-ray spectroscopy, and X-ray photoelectron spectroscopy. The nanodroplet size and morphology were determined by dynamic light scattering and neutron scattering. Our results show that the nanoparticle size can be controllably varied from ~4 to 20 nm with < 3% dispersity by manipulating the water nanodroplet size, while maintaining the particle shape and Fe/Pt ratio within < 3.5% of the precursor molar ratios. The low dispersity and high uniformity in particle shape enables the formation of close-packed nanoparticle assemblies. The nanoparticles were coated with a 2 to 10-nm silica shell by introducing tetraethyl oxysilicate into the microemulsion enhances nanoparticle thermal stability. The shell readily adapts the nanoparticles to surface functionalization with organosilanes, facilitating the formation of organized nanoparticle assemblies on chemically patterned substrates. Annealing the core-shell particles to 650 °C forms the chemically ordered L10 phase, yielding high magnetic coercivity values of ~850 mT. High-resolution electron microscopy reveals that annealing also induces coalescence of multiple clusters initially present within each nanoparticle, but only within the

confines of the silica shell, thereby preserving the overall particle shape and size. Such simultaneous control over structural, chemical and morphological features of magnetic nanoparticles is attractive for assembling stable magnetic nanoparticle assemblies in desired substrates and matrices for developing multifunctional magneto-composites and data storage devices.

9:00 AM Q6.3

L_{10} Order In FePt Thin Films And X-Ray Rapid Thermal Annealing (XRTA). Rosa Alejandra Lukaszew¹, Jonathan Skuza¹, Cesar Clavero², Alfonso Cebollada² and Eric Dufresne³; ¹Physics and Astronomy, University of Toledo, Toledo, Ohio; ²IMM, Madrid, Spain; ³MHATT, APS, ANL, Argonne, Illinois.

Highly ordered L_{10} FePt thin films and nano-structures are important for magneto-recording applications because this ordered phase exhibits very large magnetic anisotropy.¹ One possibility to achieve high degree of L_{10} order in epitaxial but chemically disordered films is to perform annealing treatments.² One interesting variation of such treatments is rapid thermal annealing (RTA). RTA is widely used for electronic materials processing, from the activation of dopants to the healing of lattice defects caused by ion implantation. Here we describe an innovative application of x-ray undulator radiation to simultaneously perform RTA and to probe structural changes that occur during annealing. This is made possible by the high power-density of undulator beams ($\sim 100 \text{ W/mm}^2$), combined with their excellent properties as a probe of crystal structure (especially collimation and high-brightness). XRTA is similar to laser annealing, but there is a unique advantage in that the x-ray energy can be tuned to enhance the coupling into the absorption edge of a particular species, thereby permitting selective annealing of buried layers and nanostructures. In our studies at the MHATT-CAT beam line we have used XRTA to enhance the degree of L_{10} chemical order in epitaxial (001) FePt thin films. Using a (111) Silicon crystal in the diffractometer analyzer arm, we were able to monitor the x-ray diffraction pattern in real time as the samples were heated by the undulator x-ray beam. The undulator beam (1st harmonic $\sim 10 \text{ keV}$) heated a 1 mm^2 spot in the sample to $\sim 1000 \text{ C}$ in a few seconds. We observed the enhancement of the $fcc - fct$ transition with 30 msec temporal resolution in Bragg geometry. The results demonstrate that undulator radiation offers a unique possibilities for materials processing, particularly the ability to use the same beam for heating and as a structural probe. This work was partially supported by NSF-DMR (Grant #0355171), the American Chemical Society (PRF grant # 41319-AC) and the Research Corporation Cottrell Scholar award. ¹ A. Cebollada, R. F. C. Farrow, and M. F. Toney, *Magnetic Nanostructures*, edited by H. S. Nalwa (American Scientific Publishers, 2002), pp. 93 - 118. ² Xiao-Hong Xu, Hai-Shun Wu, Xiao-Li Li, Fang Wang and Jing-Fang Duan, *Physica B* **348**, 436 (2004).

9:15 AM Q6.4

Reconstruction of the Magnetization Distribution of Small CoPt Patterns via Magneto-optic Imaging and Magnetic Force Microscopy. Christian Jooss¹, Sebastian Dreyer¹, Sven Schnitger¹, Jonas Norpoth¹, Sibylle Sievers², Martin Albrecht² and Uwe Siegner²; ¹Institute of Materials physics, University of Goettingen, Goettingen, Germany; ²Physikalisch-Technische Bundesanstalt, Braunschweig, Germany.

A combined magnetic mapping technique, consisting of magneto-optical imaging, magnetic force microscopy and inverse mathematical methods is presented. It allows for the reconstruction of the magnetization distribution of patterned hard magnetic thin films. The magneto-optic imaging technique is based on garnet films with a high Faraday rotation. It measures the normal component of the magnetic flux density on length scales from mm down to 300 nm and therefore allows is suitable for e.g. the imaging of whole arrays of magnetic elements. The MFM provides fine-scale magnetic information down to nanometer resolution. Together with forward and inverse solutions of the magnetostatic equations, this approach allows for a non-destructive, non-invasive quantitative imaging of the magnetization distribution in hard magnetic films. The potential of the method is demonstrated with patterns of CoPt films with high uniaxial perpendicular anisotropy and artificial patterns of hard magnetic CoPt dots in a soft magnetic Permalloy thin film environment. All structures are patterned via electron beam lithography and ion beam etching. Particular emphasis is put on the quantitative study of collective behaviour of arrays of small hard magnetic dots in different geometries and soft magnetic environments. S. Sievers, M. Albrecht, U. Siegner, S. Dreyer and Ch. Jooss, *J. Appl. Phys.*, submitted.

9:30 AM Q6.5

c-Axis Oriented, Isolated L_{10} -FePt Nanoparticle Monolayers on TiN Underlayers with Controlled Grain Sizes. Suguru Noda

and Yoshiko Tsuji; Department of Chemical System Engineering, The University of Tokyo, Tokyo, Japan.

L_{10} -FePt is a promising material for high density perpendicular magnetic recording media owing to its excellent magnetic property, and intensive efforts have been made in developing fabrication processes of FePt with highly-controlled nanostructures. We have reported that c-axis oriented, isolated L_{10} -FePt nanoparticle monolayers can be formed on (200)-oriented polycrystalline TiN underlayers by conventional sputtering method, where single FePt nanoparticles grew on single TiN grains with local epitaxial relationship [1]. Because TiN has a melting point as high as 3563 K, it can have grain sizes as small as a few nanometers even at high temperatures needed for chemical ordering of FePt. In this presentation, we will report the controllability of TiN nanostructures by deposition conditions such as temperature, bias voltages, sputtering gases, and adhesion layers. An example is a 5-nm-thick TiN layer with an in-plane grain size of 5 nm. Then the effect of TiN underlayers on nanostructures and magnetic properties of FePt grown on them will be discussed. Finally, the approach to increase each crystallite volume by making multi-epitaxial (FePt/TiN)_n columns will be introduced. Preparation of FePt nanoparticles on arbitrary substrates by conventional sputtering would be a promising candidate as a practical fabrication process of recording media. [1] S. Noda, Y. Tsuji, A. Sugiyama, A. Kikitsu, F. Okada, and H. Komiya, *Jpn. J. Appl. Phys.*, in press.

9:45 AM Q6.6

Indirect Exchange Interaction in Granular Permalloy Films. Anatoli Pogorily^{2,1}, Anatoli Kravets², Yuri Dziedzija², Olena V Shypil¹ and Chester Alexander¹; ¹MINT Center, University of Alabama, Tuscaloosa, Alabama; ²Physics of Thin Films, Institute of Magnetism, Kyiv, 03142, Ukraine.

It has been shown by numerous experimental data that cooperative properties of the ferromagnetic granular system are affected significantly by the conductive properties of a nano-composite matrix. These results are mainly determined by an indirect exchange interaction in the magnetic sublattice via conductive electrons. This interaction is especially notable in ferromagnetic granular systems with granules dispersed in a conductive nonmagnetic matrix. System with small granules (up to 50 nm) of magnetic material, regularly distributed in a nonmagnetic matrix can serve as a basis for super dense recording media. We found that the maxima of graphs of magnetoresistance vs composition for granular Py films in conducting (Ag) and nonconducting (Al_2O_3) matrixes are shifted in Py composition up to $\sim 10 \text{ vol\%}$. It is known that the maximum of magnetoresistance in these films is close to the composition where the interaction between granules disappears. We measured Ferromagnetic Resonance for two sets of films, Py-Ag and Py-(Al_2O_3), using orientations of the magnetic field parallel and perpendicular to the film surface, and found that indeed the interaction between granules in conducting (Ag) matrix disappears at a composition $\sim 22 \text{ vol\%}$ Py, whereas for nonconducting (Al_2O_3) matrix it disappears at $\sim 34 \text{ vol\%}$ Py. To get agreement between theoretical and experimental dependences of FMR resonance fields we use a model based on the introduction of an effective field caused by conductive electrons that are common to the whole material and that are present in the whole inter-ion space, assuming that the shape of ferromagnetic granules is spherical and that they have weak crystal anisotropy. We also assume that the magnetic moments of granules are influenced by an effective field: $H^{\text{eff}} = H - 4\pi M_s e_s + h$ (1) where H is the external magnetic field, the second term represents the demagnetizing field of the film and the term h is formally introduced to describe the indirect exchange field from the electron subsystem. To determine the value of indirect exchange effective field, we introduce h as: $h = J^2 \chi M = kM$ (2) where J is a constant of the inter-band $s - d$ exchange interaction, and χ is the paramagnetic susceptibility of the conductive electron subsystem. A simple evaluation of the effective indirect exchange field was carried out by analysis of the magnetization curves of granular films. Good correlation of experimental data and calculations showed that an indirect exchange interaction in a granular system with a conductive matrix helps to establish magnetic correlation long before the percolation threshold is achieved.

10:30 AM Q6.7

Ferromagnetism from a Co-porphyrin Supramolecular Assembly. Anthony N Caruso, Doug Schulz, Pam Jeppson, Laura Jarabek and Douglas Chrisey; North Dakota State University, Fargo, North Dakota.

Ferromagnetism from an air-stable supramolecular assembly of a cobalt porphyrin-based system has been observed above room temperature with saturation not observed up to 7 Tesla. Low temperature (5K) measurements indicate an extremely strong exchange mechanism from the ligand fields and this observation will be a focal point of this talk. We hypothesize that the organic

assembly provides a scaffolding to hold the transition metal centers in place for direct exchange. In addition, two rather strange responses are observed for this system: (1) a metamagnetic transition occurs at 130K; and, (2) classical exchange bias is observed and is enhanced for field cooled samples. Thin films and chemical variations will also be discussed in the context of advantages for future spintronic devices that will use organic materials.

10:45 AM Q6.8

Fabrication of Ordered Mesoporous Silica with Encapsulated Iron Oxide Particles via Doped Block Copolymer Templates in Supercritical Carbon Dioxide. David M Hess¹, James J Watkins¹, Rajesh R Naik² and Melanie Tomczak²; ¹chemical engineering, University of Massachusetts-Amherst, Amherst, Massachusetts; ²Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright Patterson Air Force Base, Ohio.

Encapsulation of ferritin within mesoporous silica provides a potential route to devices that rely on isolated anti-ferromagnetic metal oxide clusters. Ferritin is a ubiquitous iron storage protein that is made up of a self-assembling protein shell 12 nm in diameter and with an 8 nm cavity that contains an iron oxide particle. Recently ferritin has been used to form ordered arrays of iron nanoparticles. Upon dipping a substrate into a solution, ferritin aligns in a hexagonal type monolayer arrangement. Upon heating, the shell is removed and the spherical iron oxide nanodot remains. Recently, our group has reported a new approach for fabricating mesoporous silicates involving the selective condensation of a silica precursor in the hydrophilic domain of a highly ordered amphiphilic block copolymer using supercritical carbon dioxide as a delivery medium. In this approach template organization silica network formation occur in discreet steps. Consequently the template can easily be doped with active components in specific sub-domains prior to silica infusion and removal of the template by calcination. In this work, a poly(ethylene oxide)-poly(propylene oxide)-poly(ethylene oxide) triblock copolymer was doped with horse spleen ferritin and a low concentration of a p-toluenesulfonic acid catalyst. The template was then spin-casted onto a silicon wafer. Upon drying the block copolymer undergoes microphase segregation and both the acid catalyst and ferritin partition into the hydrophilic domain. The doped template was then exposed to a solution of tetraethyl orthosilicate (TEOS) in supercritical carbon dioxide at 60 oC and 125 bar. TEOS selectively condensed in the PEO domain to yield a nanocomposite material, which upon calcination yielded an iron oxide-doped, well-ordered, mesoporous silica film. TEM and XRD analysis indicated that the structure of the mesoporous silica matrix was dependent upon the concentration of ferritin dopant. XRD revealed the presence of crystalline iron oxide within the mesoporous support. Samples were also characterized using a semiconducting quantum interference device (SQUID) and were found to possess interesting magnetic properties.

11:00 AM Q6.9

A Novel Polymer Mediated Approach for the Synthesis of Magnetic Nanoparticles. Suresh Valiyaveetil^{1,2,3}, Swaminathan Sindhu³ and Subbiah Jagadesan²; ¹National University of Singapore, Singapore, Singapore; ²Department of Chemistry, National University of Singapore, Singapore, Singapore; ³NUSNII, National University of Singapore, Singapore, Singapore.

Magnetic nanoparticles are of important and attracted researchers from various fields due to their promising applications in high density magnetic recording media, contrasting agents in MRI, drug delivery and hyperthermia for cancer therapy. Owing to their application potential it is essential to control the size and shape of the magnetic nanoparticles with better thermal and chemical stability and form stable colloidal suspension. Herein we develop a facile method for the production of oxidatively stable cobalt (Co) (10-15 nm) and nickel (Ni) nanoparticles (4-5 nm) by a polymer mediated synthetic approach. It is noted that no external reducing agent is required here for the production of sub-nanometer sized magnetic nanoparticles. The oxidation state of the resulting nanoparticle can be controlled in ambient condition by wisely selecting the polymers with appropriate functional moieties. In this approach the polymer play multi roles such as reducing or oxidizing agent (depend on the functional group) as well as structure directing agent. HRTEM, MFM and essential analysis were done to prove the oxidation state and magnetic nature of the nanoparticles. Reference: [1] M. Anderson, J. S. Pedersen, A. E. C. Palmqvist, Langmuir, ASAP article (Web release Oct. 20th 2005. [2] M. Yamada, M. Maesaka, M. Kurihara, M. Sakamoto, M. Miyake, Chem. Commun., 2005, 4851. [3] N. Wu, L. Fu, M. Su, M. Aslam, K. C. Wong, V. P. Dravid, Nano Letters, 2004, 4, 383.

11:15 AM Q6.10

Development of Block Co-Polymers as Self-Assembling Templates for Magnetic Media and Spin-Valves. Martin Gerard Bakker^{1,2}, Vishal Warke^{1,2}, David Nikles^{1,2}, Jimmy

Mays³ and Phillip Britt³; ¹Center for Materials for Information Technology, The University of Alabama, Tuscaloosa, Alabama; ²Department of Chemistry, The University of Alabama, Tuscaloosa, Alabama; ³Center for Nanophase Materials Science, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Poly(styrene)-Poly(methylmethacrylate) block co-polymers (PS-b-PMMA) of appropriate block length and PS to PMMA ratio self-assemble into a 2-D hexagonal phase in which the PS majority phase is continuous and surrounds cylinders of the minority, PMMA phase. By UV irradiation and washing with acetic acid it is possible to remove the minority phase to leave empty channels. It is also possible to rearrange the PMMA phase with acetic acid to leave somewhat smaller pores. For most substrates the interactions between the polymer and the substrate surface are such that one block is preferentially adsorbed to the substrate resulting in alignment of the PMMA domains parallel to the substrate surface. It is possible to orient the polymer perpendicular to the surface by first adding a thin film of a random PS-PMMA co-polymer before applying the PS-b-PMMA block co-polymer. However thin films of the random PS-PMMA do not give good surface coatings, and thicker films are generally too thick for the pores in the PS-b-PMMA block co-polymer to be propagated to the substrate surface. For a few substrates, thin PS-b-PMMA films naturally adopt a perpendicular orientation after annealing, washing with acetic acid produces arrays of pores of diameter as small as 3 nm. For a number of other substrates the interaction between the polymer blocks and the surface is such that upon annealing the polymer rearranges to form micron sized domains which are not polymer coated, surrounded a areas which have a thicker polymer coating. We have observed this behavior with both carbon coated substrates and with ITO glass substrates. In both cases the areas of polymer are perpendicularly oriented, and upon washing with acetic acid give rise to pores that extend completely through the polymer film. In some cases films on ITO glass are continuous even after annealing. After washing with acetic acid it was possible to electrodeposit nickel into the pores to give nickel nano-pillars of 18 nm diameter.

11:30 AM Q6.11

Room Temperature Ferromagnetism in Ge-based Nanowires. Olga Kazakova¹, Jaideep S Kulkarni², Justin D Holmes² and Sergej O Demokritov³; ¹NPL, Teddington, Middlesex, United Kingdom; ²UCC, Cork, Ireland; ³WWU, Munster, Germany.

Spintronics requires fabrication of ferromagnetic nanostructures that can transport spin-polarized carriers at room temperature, be electrically tunable and easily compatible with existing silicon manufacturing technologies. The most direct method to induce spin-polarized electrons into a semiconductor is by introducing transition metal dopants, producing a dilute magnetic semiconductor (DMS) [1, 2]. Extensive research has been carried out in order to create DMS materials with well-established room temperature ferromagnetism. Despite several encouraging results, DMS materials are still struggling to reliably achieve the desired high Curie temperature. Here we report the first time observation of room temperature ferromagnetism in group-IV DMS materials in the form of 1D structures. We investigate magnetic properties of Ge nanowires (NWs) having a smallest diameter of 35 nm and length of 60 μ m, synthesised within the pores of anodised aluminium oxide (AAO) templates [3] and doped with various transition metals (Mn, Co or Cr). Structural analysis of the NWs showed the existence of a highly crystalline germanium host lattice containing discrete dopant atoms. The dependences of the magnetic characteristics of the NWs on their diameter, transition metal concentration and preparation details were investigated by means of SQUID magnetometry. Of the all studied magnetic impurities, Mn-doped NWs are of particular interest, as these structures display well-pronounced ferromagnetic properties at room temperature [4], whereas a typical transition temperature for GeMn thin films is only about 110 K [5]. Ferromagnetic ordering reaches a maximum at intermediate Mn concentrations followed by a decay in the magnetic properties at $x = 5\%$. The effect of interface related anisotropy in NWs of different diameters was also studied. By eliminating the surface strain we were able to improve ferromagnetic performance of NWs at room temperature. We also show that room temperature ferromagnetism was preserved after post-annealing, meaning GeMn NWs are compatible with present CMOS technology. The magnetic properties of the NWs can be understood by considering the influence of co-dopant non-magnetic impurities, i.e. oxygen and carbon, as well as confinement effect at the interfaces. The observation of ferromagnetic properties in Mn-doped Ge NWs at 300 K as well as compatibility of germanium and silicon allow straightforward integration of Ge NWs into mainstream electronics and open the way for room-temperature spintronic devices. 1. A. H. Macdonald, et al., Nature Materials 4, 195 (2005). 2. S. J. Pearton, et al., Physica B 340-342, 39 (2003). 3. J. S. Kulkarni, et al., Chem. Mat. J. Mater. Chem. 17, 3615 (2005). 4. O. Kazakova, et al., Phys. Rev. B. 72, 0944415 (2005). 5. Y. D. Park, et al., Science 295, 651 (2002).

11:45 AM Q6.12

Diluted Magnetic Semiconductor Zn(Mn)O Nanowire Array From A Self-Formed ZnO Substrate. Jingjing Liu, Minhui Yu and Weilie Zhou; AMRI/Chemistry, University of New Orleans, New Orleans, Louisiana.

Well-aligned diluted magnetic semiconductor (DMS) Zn_{1-x}Mn_xO nanowires have been successfully fabricated from a self-formed ZnO substrate using chemical vapor deposition (CVD) method. The as-synthesized Mn-doped ZnO nanowires were characterized by field emission scanning electron microscopy (FESEM) and transmission electron microscopy (TEM). The nanowires are well-aligned and are perpendicularly-grown along the c-axis having single crystalline structure. Electron energy X-ray dispersive (EDS) analysis, X-ray diffraction (XRD) spectrometry and TEM analysis clearly showed that Mn was successfully doped in the ZnO nanowires and substrate. Ferromagnetic ordering of the as-synthesized Zn_{1-x}Mn_xO nanowire arrays was observed at 5 K with Curie temperature of 44 K and room temperature by superconducting quantum interference device (SQUID) measurement due to different synthesis condition. The DMS nanowire arrays with room temperature ferromagnetic ordering have strong applications in spintronic nanodevices.

SESSION Q7: Dilute Magnetic Semiconductors, Oxide Heterostructures, and Multiferroics
Thursday Afternoon, April 20, 2006
Room 3020 (Moscone West)

1:30 PM Q7.1

Exchange Biasing with Magnetoelectric YMnO₃ Epitaxial Films. Xavier Marti¹, Florencio Sanchez¹, Nico Dix¹, David Hrabovsky¹, Vassil Skumryev², Maria-Victoria Garcia-Cuenca³, Cesar Ferrater³, Manuel Varela³, Ulrike Luders⁴, Jean Francois Bobo⁴ and Josep Fontcuberta¹; ¹ICMAB-CSIC, Bellaterra, Spain; ²Institut Catala de Recerca i Estudis Avancats, Barcelona, Spain; ³Fisica Aplicada i Optica, Universitat de Barcelona, Barcelona, Spain; ⁴Onera, Toulouse, France.

Biferroic materials are currently receiving much attention as they show the existence of ferroelectricity and magnetic order. Among oxides, the intriguing coexistence of ferroelectricity and antiferromagnetism in hexagonal YMnO₃ has been much discussed. However, recently research has been also driven on the orthorhombic phase of this oxide (o-YMnO₃) as it displays substantial changes on the dielectric constant close to the antiferromagnetic order temperature which make it very appealing for a new generation of magnetoelectric devices. Unfortunately, in bulk form o-YMnO₃ can only be prepared under very high pressure thus facing severe problems of integration. Here, we report on growth of YMnO₃ films. We will show first that by appropriate selection of substrates, the o-YMnO₃ epitaxial films can be stabilized. Moreover, we will show that by appropriate choice of the substrate orientation, the texture of the YMnO₃ can be tuned. Magnetic characterization of these films reveals the presence of a magnetic transition at about 40K from a paramagnetic state to a canted antiferromagnet. Aiming to integrate the magnetoelectric YMnO₃ with ferromagnetic oxides in a new generation of magnetic devices, we have successfully grown epitaxial o-YMnO₃ films on the SrTiO₃ substrates buffered with either Pt or ferromagnetic SrRuO₃ epitaxial film or capped with Permalloy. When measuring YMnO₃/SrRuO₃ bilayers a well defined exchange bias field appears. The exchange bias field decreases with temperature and vanishes at around 40 K, the Néel temperature of the o-YMnO₃; the magnetoelectric character of YMnO₃ offer the possibility of controlling the exchange bias and thus magnetic switching, by an electric field.

1:45 PM Q7.2

Magneto-Electric Coupling in Multiferroic Oxide Films by Photoemission Electron Microscopy. Tong Zhao¹, A. Scholl², F. Zavaliche¹, H. Zheng¹, M. E. Barry¹, M. P. Cruz¹, Q. Zhan¹, Y. H. Chu¹, A. Doran², L. W. Martin¹ and R. Ramesh¹; ¹Department of Physics and Department of Materials Science and Engineering, University of California, Berkeley, California; ²Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, California.

Multiferroic materials, showing simultaneous (anti-)ferromagnetic and ferroelectric ordering, have attracted much attention. The coupling between these two ordering parameters has great potential for novel electronic device applications. On the other hand, the new physics behind the materials and phenomena is interesting itself from the fundamental science point of view. To probe the magneto-electric coupling, therefore, is with great interests. In this work, a unique technique, namely Photoemission Electron Microscopy (PEEM) at the Advanced Light Source of the Lawrence Berkeley National Laboratory was utilized to probe the magneto-electric coupling in a multiferroic

nanostructure comprised of ferrimagnetic CoFe₂O₄ pillars embedded in ferroelectric BiFeO₃ matrix which was prepared by pulsed laser deposition through a self-assembly process. Piezoelectric force microscopy (PFM) was used to study the ferroelectric property, and to switch the ferroelectric polarization in the BiFeO₃ matrix of the nanostructure by applying an electrical voltage through the PFM tip. The magnetic structure of the CoFe₂O₄ pillars in the nanostructure was measured by PEEM with a circularly-polarized X-Ray. The nanostructure was magnetized in a magnetic field to align the magnetization of the CoFe₂O₄ pillars. Then an electrical voltage was applied to a selected area to switch the ferroelectric polarization of the BiFeO₃ matrix. A clear magnetic circular dichroism was observed at both Co and Fe L edges of the CoFe₂O₄ pillars between the poled and unpoled areas. This is a strong evidence that the magnetization of the CoFe₂O₄ pillars were switched by switching the ferroelectric polarization of the BiFeO₃ matrix. The magneto-electric coupling as a function of electric voltage and CoFe₂O₄ pillar size was studied. X-Ray absorption spectrum was also measured to study the cation site occupancy and valence state in the CoFe₂O₄ spinel structure. Linearly polarized X-Ray was used to probe the antiferromagnetic-ferroelectric coupling in a BiFeO₃ thin film. A clear linear dichroism and a similar domain structure to the PFM measurement were observed before and after electrical poling on the BiFeO₃ film, implying an antiferromagnetic-ferroelectric coupling in this material. This work is supported by an ONR-MURI and a LBL-LDRD.

2:00 PM Q7.3

Multiferroic Characteristics of Highly Oriented ferrite-ferroelectric Multilayered and Composite Films Deposited by Laser Ablation. Sarath Witanachchi, H S Nagaraja, R Heindl, H Srikanth and Pritish Mukherjee; Department of Physics, University of South Florida, Tampa, Florida.

Coupling of ferroelectricity and ferromagnetism in a single system presents interesting applications in spintronics and sensors. Ferrimagnetic BaFe₁₂O₁₉ (BaM) and ferroelectric Ba_{0.5}Sr_{0.5}TiO₃ (BSTO) are reasonably compatible materials to fabricate multilayered structures to investigate such coupling. In this study we have used a dual-laser ablation process to deposit single and multilayered films on various substrates that included A-plane and C-plane sapphire, 96% polycrystalline Al₂O₃ and MgO. Single and multilayer films deposited under optimum growth temperature and oxygen pressure showed high degree of orientation without any post deposition treatment. Low-angle x-ray diffraction and rocking curve measurements confirmed the epitaxial-like growth on sapphire substrates. While BSTO films were observed to grow epitaxially on MgO, films deposited from an ablation target that contained 50-50 mixture of BaM and BSTO showed the formation of separate phases with random orientation. However, when the composite film was deposited on MgO with a thin BSTO layer, the BaM and BSTO grains in the film became highly oriented. A versatile microwave probe station has been used to investigate the high-frequency characteristics of the films with applied parallel and perpendicular magnetic as well as electric fields. Magnetic hysteresis studies of multi layered structures at various field orientations showed large coercivities. Correlation between the microstructure of the films and the ferromagnetic and ferroelectric properties will be presented.

2:15 PM Q7.4

Self-Assembled BiFeO₃-CoFe₂O₄ Thin Film Nanostructure Growth Evolution. S. Y. Young¹, L. Salamanca-Riba¹ and H.

Zheng²; ¹Materials Science and Engineering Department, University of Maryland, College Park, College Park, Maryland; ²Materials Science and Engineering Department, University of California Berkeley, Berkeley, California.

We report on the mechanism of the self-assembly of BiFeO₃-CoFe₂O₄ (BFO-CFO) ferromagnetic thin film nanostructures observed by high-resolution transmission electron microscopy, and suggesting how the growth evolution of the CFO columnar structure forms. The BFO-CFO thin films were deposited on single crystal SrTiO₃ (001) substrates using pulsed laser deposition at a substrate temperature and deposition rate of 700 degree C and ~5nm/min, respectively. In the early stages of growth CFO domains form with pyramidal-like shape covered by BFO. After approximately 5 mins of continuous deposition, the nanocomposite rearranges and diffusion takes place to form a self-assembly of CFO columns that extend to the surface of the film. These columns have a preferred, more stable faceted shape and are surrounded by a BFO matrix. There also exist a thin layer of a few atomic layers of BFO at the interface between the CFO columnar structure and the substrate. This layer helps relax the misfit strain between them. Magnetic properties of the nanocomposites samples will also be presented.

2:30 PM Q7.5

Oxygen Thermodynamics and Rapid Growth of High Quality Epitaxial BiFeO₃ Thin Films. Meicheng Li^{1,2}, Ahmed

Kursumovic¹, Xiaodong Qi¹, Mark G. Blamire¹ and Judith L. MacManus-Driscoll¹; ¹Dept. of Materials Science, University of Cambridge, Cambridge, United Kingdom; ²Department of Materials Physics and Chemistry, Harbin Institute of Technology, Harbin, China.

Much attention is paid to the multifunctional materials, such as so-called magnetoelectric materials, which have many potential applications. BiFeO₃ is one of only a few materials in which (anti)ferromagnetism and ferroelectricity coexist. In order to control and improve the characteristics, it is necessary to understand the factors which influence the magnetoelectric properties. The study of oxygen nonstoichiometry of BiFeO₃ has been carried out employing a solid-state ionic titration technique, which involved the yttria stabilized zirconia (YSZ) solid electrolyte. X-ray diffraction data show that BiFeO₃ phase decomposes to a new Bi₂₅FeO₄₀ phase at low oxygen pressure. Besides the determination of oxygen nonstoichiometry in the decomposed components, we also carried out selective doping studies and studied the influence of these factors on the ferromagnetic and ferroelectric behaviour, and leakage current. We also used a novel hybrid liquid phase epitaxy approach to grow good quality films at a rate of up to 2nm/s.

2:45 PM Q7.6

Temperature and Bias Dependence of Epitaxial Magnetic Tunnel Junctions with Paramagnetic Barriers.

Brittany B Nelson-Cheeseman¹, Lisa Alldredge^{2,1}, Rajesh Chopdekar^{2,1} and Yuri Suzuki¹; ¹Materials Science and Engineering, University of California - Berkeley, Berkeley, California; ²Applied Physics, Cornell University, Ithaca, New York.

Epitaxial oxide magnetic tunnel junctions composed of La_{0.7}Sr_{0.3}MnO₃ (LSMO) and Fe₃O₄ electrodes with paramagnetic NiMn₂O₄ barriers were fabricated in order to study how magnetic moments in the barrier layer affect the junction magnetoresistance (JMR). It has been shown that, due to an isostructural interface with Fe₃O₄, spinel barrier layers give rise to significant enhancement of the JMR in Fe₃O₄ based junctions by decreasing the spin scattering at the barrier-electrode interface. Previously, JMRs of up to ~25% at 60K have been shown in junctions with paramagnetic CoCr₂O₄ barriers. In this study, we have synthesized epitaxial NiMn₂O₄ thin films whose T_C of 55K is suppressed from the bulk value of 100K. Transitions in magnetization hysteresis loops coincide well with sharp and large transitions in magnetoresistance. Furthermore, the antiparallel LSMO-Fe₃O₄ magnetization configuration is the low resistance state, which confirms that Fe₃O₄ is a negatively spin-polarized material. We observed JMR up to ~30% at 35K in LSMO / NiMn₂O₄ / Fe₃O₄ junctions. A peak in the JMR is observed as a function of temperature; this peak is attributed to the onset of the Verwey transition in the Fe₃O₄ electrode. Three different types of bias dependences of the JMR manifest themselves as a function of decreasing temperature, and occur with varying degrees in different junctions. In the high temperature regime, the JMR decreases as a function of increasing magnitude of the bias with slight asymmetry due to the difference in barrier heights at the two electrode-barrier interfaces. At intermediate temperature, a zero-bias anomaly appears with a maximum JMR at +/- 50-100mV. As the temperature is lowered, the zero-bias anomaly disappears and JMR again decreases monotonically as a function of increasing magnitude of the bias with little asymmetry. These different bias dependences can be attributed to the competition between direct tunneling and inelastic hopping transport mechanisms as well as the opening of a gap in the density of states in the Fe₃O₄ as the temperature is lowered below the Verwey transition.

3:30 PM Q7.7

Design and Synthesis of a Novel Multilayer System for Low-field Giant Magnetoresistive Application. Ashutosh Tiwari, Materials Science & Engineering, University of Utah, Salt Lake City, Utah.

During the last few decades, extensive research has undergone to discover efficient materials and devices, which can exhibit high magnetoresistance. A tremendous boost to these efforts occurred by the discovery of colossal magnetoresistance in doped perovskite manganates La_{1-x}A_xMnO₃ (A: Sr, Ba, Ca). These oxides undergo a Metal-insulator transition at T_{M-I} closely followed by a Ferromagnetic-paramagnetic transition at T_C (T_{M-I} ~ T_C) and exhibit giant magnetoresistance at the same temperature. However in order to realize giant magnetoresistance in these materials, very high magnetic field is required. High magnetic field requirement poses a serious problem in making any practical use of manganates in magnetic devices and sensors, which need to be operated at low fields. In this talk we will report the growth of a new class of superlattice structure, consisting of alternate layers of La_{0.7}Sr_{0.3}MnO₃ (LSMO) and ZnO, which exhibits giant magnetoresistance at low fields. Giant magnetoresistance of >250% has been observed in these structures on

the application of just ~400 Gauss of magnetic field over the broad temperature range 15-200 K with a maximum of about 1100% at around 100K. Observation of giant magnetoresistance at such low magnetic fields is a groundbreaking step in the field of novel magnetic materials and devices.

3:45 PM Q7.8

Induced Ferromagnetism at the Interface of Paramagnetic CoCr₂O₄ Epitaxial Thin Films. Rajesh Vilas Chopdekar^{1,2}, Marco Liberati^{3,4}, Yayoi Takamura², Elke Arenholz⁴, Andreas Scholl⁴, Andrew Doran⁴, Yves Idzerda³ and Yuri Suzuki²; ¹Applied and Engineering Physics, Cornell University, Ithaca, New York; ²Materials Science and Engineering, UC Berkeley, Berkeley, California; ³Physics, Montana State University, Bozeman, Montana; ⁴Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, California.

Previous work on epitaxial manganite (La_{0.7}Sr_{0.3}MnO₃)-magnetite (Fe₃O₄) magnetic tunnel junctions (MTJs) have shown large junction magnetoresistance (JMR) from the use of a spinel-structure paramagnetic insulator(1) as the tunnel barrier. However, the use of CoCr₂O₄ (CCO) as the barrier in an isostructural Fe₃O₄-CCO-Fe₃O₄ trilayer(2) yielded small JMR. In addition, the trilayer exhibited room-temperature exchange coupling between the ferromagnetic electrodes across the 6nm thickness of the barrier. Such behavior was puzzling in light of the CCO bulk Curie temperature (T_C=95K), and single layer CCO thin films that showed largely suppressed magnetization as measured by a SQUID magnetometer. We have grown 40nm thick layers of the ferromagnetic electrode materials, La_{0.7}Sr_{0.3}MnO₃ and Fe₃O₄, as well as CCO by pulsed laser deposition on (110) SrTiO₃ single crystalline substrates. Furthermore, 3nm thick CCO capping layers were grown on 40nm thick electrode films to study the magnetism and coupling at the paramagnet-ferromagnet interface. Soft x-ray magnetic circular dichroism (XMCD) spectroscopy at the Advanced Light Source indicated that octahedrally coordinated Cr atoms were strongly polarized by the underlying ferromagnetic oxide layers, but the tetrahedrally coordinated Co atoms were less strongly polarized. While the perovskite-structure manganite film weakly enhanced the ferromagnetism of the CCO capping layer, the commensurate spinel Fe₃O₄-CCO interface provided unexpectedly strong coupling to above room temperature. Domain images taken in the photoemission electron microscope confirmed that domains of magnetite ferromagnetically coupled to CCO capping layers with thicknesses of 3nm and 6nm. The domain structure in CCO persisted up to 500K on the Cr L3 edge, well above the T_C of CCO, but was not seen on the Co L3 edge even at room temperature. We attributed this strong inducement of ferromagnetic order in CCO to interface coupling to octahedrally coordinated Mn or Fe at electrode-barrier interfaces. Defects such as anti-phase boundaries at a perovskite-spinel interface suppressed the exchange coupling of the paramagnetic capping layer, but the high quality interface between spinel-structure oxides allowed for the persistence of the ferromagnetic state up to 6nm away from the ferromagnet-paramagnet interface. Thus the isostructural nature of the spinel-spinel CCO-Fe₃O₄ interface enhanced JMR in LSMO-CCO-Fe₃O₄ junctions by reducing structural disorder, but the strongly coupled Fe₃O₄-CCO-Fe₃O₄ junctions served as a spin-filter device, rather than a true MTJ with a non-magnetic barrier separating two distinct ferromagnetic electrodes.

4:00 PM Q7.9

Ultrafast Carriers Dynamics in GaSb/Mn Random Alloys. Shuji Ye, Joseph Knab, Jing-Yin Chen, Andrea Markelz, Shumin Wang, Miyeon Cheon and Hong Luo; Department of Physics, University at Buffalo SUNY, Buffalo, New York.

Research in dilute magnetic semiconductors continues to pursue development of spintronic materials with multifunctional properties. The ferromagnetism is carrier mediated which can be controlled by electronic or optical carrier injection. The InAs/GaSb system in particular offers unique integration with telecom wavelengths. While above room temperature ferromagnetism for GaSb/Mn digital alloys has recently been achieved, [1] overall this systems electronic properties are not yet ideal for device applications. In an effort to further understand the nature of defects within the GaMnSb system we have performed a series of time resolved reflectivity measurements on GaMnSb random alloys as a function of pump/probe wavelength and Mn concentration. Samples were MBE grown on Si-GaAs substrate with 90 nm GaAs at 580° C/220nm AlSb at 550° C/90 nm GaSb at 500° C/100 nm GaMnSb at 275° C. Mn concentrations were 1.45, 1.77, 1.86, 2.15 and 2.59%. Single color time resolved reflectivity change (ΔR/R) measurements were performed at room temperature for two wavelength regions, 1.35 - 1.60 μm and 750 - 860 nm. At the longer wavelengths we characterize carrier relaxation and recombination dynamics with some indication of metastable trapping sites whereas at the shorter wavelengths we find evidence of coherent acoustic phonon generation recently observed in InAs/Mn epilayers.[2]

The long wavelength measurements show that consistent with other low temperature (LT) grown III-Vs, the GaMnSb samples have somewhat shorter recombination times (~ 2 ps) than the high temperature grown GaSb buffer layer (~ 28 ps). The recombination time decreases with increasing doping concentration. $\Delta R/R$ time dependence is more complex for wavelengths near the band edge. An initially small positive ΔR rapidly decreases (less than 500 fs) after photo-excitation, and becomes negative. ΔR then rapidly increases and changes sign again (< 2 ps) with a final slow decay to zero. The change in reflectivity from $\Delta R < 0$ to $\Delta R > 0$ within 2 ps indicates a possible metastable defect state produced after photoexcitation. For the measurements in the 750-860 nm range, $\Delta R/R$ has periodic oscillations for both in GaMnSb and epilayer samples. The oscillation period (T) is independent of the Mn concentration, but dependent on the probe photon energy with $T = 21$ ps, 24 ps, and 25 ps for GaMnSb samples, and $T = 19.3$ ps, 20.5 ps, 22.0 ps for the epilayer sample at the probe wavelengths of 750 nm, 800 nm, and 860 nm, respectively. These values are in good agreement with recent theoretical calculations for modulation of $\Delta R/R$ due to coherent generation of acoustic phonon wavepackets. [2] [1] X. Chen, M. Na, M. Cheon, S. Wang, H. Luo, and B. D. McCombe X. Liu, Y. Sasaki, T. Wojtowicz, a J. K. Furdyna, S. J. Potashnik and P. Schiffer, Appl. Phys. Lett. 81, 511 (2002). [2] G. D. Sanders, C. J. Stanton, J. Wang, J. Kono, A. Oiwa and H. Muneoka Cond-Mat/0509152.

4:15 PM Q7.10

High Field Negative Magnetoresistance in Ni/oxide/InMnAs Tunnel Junctions. Steven J. May¹, Patrick J. Phillips² and Bruce W. Wessels^{1,2}; ¹Materials Science and Engineering, Northwestern University, Evanston, Illinois; ²Materials Research Center, Northwestern University, Evanston, Illinois.

High field magnetoresistance of tunnel junctions consisting of a ferromagnetic metal, oxide barrier and a ferromagnetic semiconductor was investigated in order to determine its origin. We have fabricated and characterized junctions utilizing ferromagnetic Ni and p-InMnAs thin films and Al₂O₃ or SiO₂ as tunnel barriers. The ferromagnetic InMnAs layers were deposited by metal-organic vapor phase epitaxy (MOVPE). I-V characteristics were measured in the tunnel junctions over a temperature range of 5 to 295 K. A conductance (dI/dV) well is observed for all samples, consistent with tunneling between a metal and a degenerate p-type semiconductor. Up to temperatures of 150 K, a negative junction magnetoresistance ($\sim 0.3\%$) was measured in fields to 0.45 T. The magnitude of the negative magnetoresistance is largest when the magnetic field is applied perpendicular to the plane of the junction. At high temperatures and fields, however, a positive magnetoresistance becomes dominant. In contrast, in Ni/oxide/p-InAs (non-magnetic) tunnel junctions and ohmic InMnAs/Ni junctions, a positive magnetoresistance is observed at all temperatures and applied fields. The negative magnetoresistance is tentatively attributed to a reduction of spin-flip scattering caused by Ni impurity ions in the oxide barrier layer. The total magnetoresistance can be fit to an equation consisting of a positive quadratic term and a negative term given by a Brillouin function. Tunnel magnetoresistance (TMR) arising from the antiparallel alignment of the ferromagnetic layers was not observed in the junctions. The absence of TMR is attributed to interlayer coupling between the Ni and InMnAs layers.

4:30 PM Q7.11

Metal-insulator Transition and Magnetic Domain in GaMnAs Epilayers. Alexandre Dourlat¹, Catherine Gourdon¹, Vincent Jeudy¹, Frederic Bernardot¹, Christophe Testelin¹, Emmanuelle Lacaze¹, Laura Thevenard², Aristide Lemaitre², Olivia Mauguin², Ludovic Largeau² and Gilles Patriarche²; ¹Institut des Nanosciences de Paris, Paris, France; ²Laboratoire de Photonique et Nanostructures, Marcoussis, France.

A remarkable feature of the magnetic properties of GaMnAs layers is the persistence of the ferromagnetic phase even below the metal-insulator transition. This apparent contradiction with carrier-induced ferromagnetism can be lifted considering that the carrier localization remains sufficiently weak to mediate the interaction between the magnetic moments. However, strong modifications of the magnetic properties between these two regimes are expected, in particular the magnetic domain patterns. Here we investigated them by low-temperature Kerr microscopy. We show in particular the strong influence of defects on the domains in the insulating regime. GaMnAs epilayers (containing 5 to 7% Mn) with the magnetic easy axis perpendicular to the layer plane were grown by molecular beam epitaxy on a thick relaxed InGaAs buffer deposited on GaAs (001). In non-optimized samples (thick GaMnAs layers of 300 nm, no post-growth treatment) the Curie temperature is around 50-60 K while the resistivity increases strongly as reducing the temperature which indicates an insulating or poor metallic character. In this case, magnetic domain reversal occurs by multiple domain nucleation and propagation along crystallographic directions. Starting from the

saturated magnetization state and decreasing the field, magnetic domains of opposite magnetization nucleate as narrow lines aligned along crystallographic $\langle 110 \rangle$ directions with a width smaller than the spatial resolution. They first grow by increasing their width which is revealed by an increased contrast. Then the magnetic domain growth proceeds by branching along $\langle 110 \rangle$ directions. AFM measurements reveal that they nucleate and propagate along some lines showing steps of height 5 to 10 nm. These lines are related to the crosshatch pattern, originating from bunches of dislocations propagating along the InGaAs/GaAs interface. We tentatively ascribe this behavior to weaker magnetic anisotropy along the lines of preferential nucleation. This may originate from a locally different strain and/or different carrier density. On the opposite, for optimized samples (thinner layers of 50 nm, with post-growth treatment) for which the Curie temperature reaches 135 K and the electrical resistivity remains finite at low temperature, the magnetic domain pattern changes drastically. Although the crosshatch pattern still exists it does not govern anymore domain shapes, nucleation and growth. Domains of opposite magnetization nucleate in the form of lamellae forming meanders. Their width increases in an irregular manner along their length. Large size homogeneous domains of several tens of microns are observed, which, together with the increase of Curie temperature, make these films promising for micro- and nanostructures patterning.

4:45 PM Q7.12

Enhanced Room Temperature Ferromagnetism in Mn- and Co-Ion Implanted Silicon. Prabhakar Bandaru^{1,2}, Joonsung Lee^{1,2}, Jeongwon Park^{1,2}, Yunjun Tang³, Sungho Jin^{1,2}, Se Ahn Song³ and James O'Brien⁴; ¹MAE, UC, San Diego, La Jolla, California; ²Materials Science program, UC, San Diego, La Jolla, California; ³Analytical Engineering Center, Samsung Advanced Institute of Technology, Suwon, South Korea; ⁴Quantum Design Inc, San Diego, California; ⁵Center for Magnetic Recording Research, UC, San Diego, La Jolla, California.

Further progress in the rapidly advancing field of spintronics is critically dependent on the availability of room temperature magnetic semiconductors. We report here, for the first time, the occurrence of ferromagnetism at room temperature in cluster free, cobalt ion implanted crystalline silicon, along with evidence of manganese induced magnetism³. Through magnetic and structural analysis it is shown that the ion implanted Si actually consists of two layers of Co- and Mn-containing silicon: (1) an amorphous Si layer on the surface, and (2) single crystalline Si beneath. The amorphous layer shows very little magnetism by itself, but yet seems to be responsible for partially canceling out or masking the ferromagnetism present in the crystalline Si. Thus, contrary to the intuition that a removal of a portion of material decreases the net magnetic moment, an etching of the amorphous Si layer, dramatically enhances the measured magnetism, by as much as 400%. The soft-magnetic character of the ferromagnetic crystalline silicon could enable spintronics at relatively low magnetic fields.

SESSION Q8: Poster Session: Magnetic Materials,
Mostly Non-metallic
Thursday Evening, April 20, 2006
8:00 PM
Salons 8-15 (Marriott)

Q8.1

Effects of Annealing Temperature on Ferromagnetism of Rutile Co-TiO₂ (100). Jisheng Pan¹, J. W. Chai¹, S. J. Wang¹ and C. H. A. Huan^{1,2}; ¹Institute of Materials Research & Engineering, Singapore, Singapore; ²Division of Physics and Applied Physics, Nanyang Technology University, Singapore, Singapore.

Diluted magnetic semiconductors (DMS) are good candidates for spintronics because they can incorporate both the charge and spin degrees of freedom. Usually, ferromagnetic semiconductors are obtained by doping magnetic impurities into host semiconductors, and several III-V and II-VI semiconductors doped with magnetic transition metals were reported to be ferromagnetic. However, most of them exhibit Curie temperature below room temperature, which limits their application in real technology. Following the theoretical prediction that ZnO would become ferromagnetic by doping with transition metals, intensive experimental work has begun on dilute magnetic oxides (DMO). A recent discovery of room-temperature ferromagnetism in Co-doped anatase TiO₂ film has motivated intensive studies on this material. In sharp contrast, there are relatively few reports in the literature on rutile Co-doped TiO₂. Since the rutile phase is thermodynamically more stable than the anatase phase, it may lead to a higher potential for technological applications. In this study, Co overlayers of ~ 3 nm have been deposited at room temperature on rutile TiO₂ (100) surfaces, followed by annealing to different temperatures. Ferromagnetic behaviour has been observed

for all samples, but the saturation magnetic moment per Co atom is seen to decrease with increasing annealing temperature up to 530 °C. In-situ photoemission studies show the interfacial reaction between the Co overlayers and TiO₂ (100) surfaces occurred upon annealing to temperatures above 400 °C. Above these temperatures, all metallic Co atoms were oxidized into the Co²⁺ state, while some Ti⁴⁺ were reduced to Ti³⁺ with increasing temperature. Therefore, the reduction of the saturation magnetic moment is accompanied by Co oxidation at high annealing temperature. However, an annealing temperature of 700 °C leads to an increase of the saturation magnetic moment. At this temperature, the formation of a new Co-Ti-O ternary compound phase is observed by high-resolution transmission electron microscopy. It is proposed that this new phase is responsible for the increase of the saturation magnetic moment. The origin of ferromagnetism is associated with the exchange interaction of magnetic ions via conduction electrons in the newly formed Co-Ti-O ternary compound rather than with the formation of Co clusters in the TiO₂ substrate.

Q8.2

La₂S₃ Thin Films from Metal Organic Chemical Vapor Deposition of Single-source Precursor. Lu Tian, Jagadees J. Vittal, Kian Ping Loh and Ti Ouyang; chemistry, national university of singapore, Singapore, Singapore.

Rare earth chalcogenides have been extensively studied because of their potential applications in electronic, optical, superconducting devices, cold cathode configurations, current controlled devices, switching devices, photoconducting cells and thermoelectric components. Also rare earth elements make them very attractive for the fabrication of new permanent magnets. Thin films of Lanthanum sulfide (La₂S₃) have been prepared from tris(N,N-diethyldithiocarbamate)(2,2-bipyridyl) lanthanum (III) precursor ([La(bipy)(S₂CNEt₂)₃]) by using metal organic chemical vapor deposition (MOCVD) on different substrates for the first time. The preparative parameters, such as substrate temperature and the nature of substrate, are optimized to get well-defined cubic phase (γ) lanthanum sulfide thin films. The optimized films are characterized by means of X-ray powder diffraction (XRPD) techniques, scanning electron microscopy (SEM), High Resolution Transmission Electron Microscopy (HRTEM) and in-situ X-ray photoelectron spectroscopy (XPS). Electrochemical impedance study indicates that the as-deposited La₂S₃ thin film shows n-type characteristics. This new route may open the way to the creation of nanostructures and avoid the use of high temperatures and toxic substances such as H₂S, CS₂.

Q8.3

Tunable Magnetic Properties of Metal Doped Gallium Oxide Nanoparticles. Vannah Katarina Rahn², Donny Magana² and Geoffrey F Strouse²; ¹Department of Chemistry, Florida State University, Tallahassee, Florida; ²Florida State University, Tallahassee, Florida.

Optical and magnetic properties of Gallium oxide has been an area of interest for potential magnetoresistive and spintronic applications. A novel synthetic route was employed in the synthesis of Gallium oxide nanoparticles using a single mode microwave and gallium acetylacetonate as a single source precursor. Gallium oxide was doped with varied concentrations of metal ions (Co, Fe) to engineer the varying magnetic properties of the alloyed nanocrystal. From powder X-ray Diffraction, we observe a single phase spinel crystal structure that remains constant despite the change in dopant concentration. From temperature dependant magnetic susceptibility analysis we observe a change in the Curie temperature with change in dopant concentration. This is expected due to an increase in exchange interactions with increase in dopant concentration level. Promising applications of this magnetically tunable material include materials for use in spintronic devices.

Q8.4

Three Dimensional Magnetophotonic Crystals on the Base of yttrium-iron-garnet Infiltrated Opals and Magnetization-Induced Second-harmonic Generation.

Oleg A. Aktsipetrov¹, Tatyana V. Murzina¹, Evgeniya M. Kim¹, Ruslan V. Kapra¹, Irina V. Moshnina¹, Dmitriy A. Kurdyukov², Savelyi F. Kaplan² and Valeri G. Golubev²; ¹Physics Department, Moscow State University, Moscow, Russian Federation; ²Ioffe Physico-Technical Institute, St. Petersburg, Russian Federation.

In this paper, three-dimensional magnetic photonic crystals based on artificial opals impregnated by Bi-substituted yttrium-iron garnet (Bi:YIG) are fabricated and characterized for their structural, optical and nonlinear magneto-optical properties. Synthetic opals formed from close-packed monodisperse amorphous SiO₂ spheres of 330 ± 5 nm in diameter, possessing fcc lattice, are used as a template for the impregnation of Bi:YIG. The opals are characterized by a regular

interconnected sublattice of voids occupying about 26% of the whole volume of the sample. For the infiltration of opals by YIG, the colloidal solution of yttrium-iron hydroxides taken in stoichiometric proportion is used. The mean size of the colloidal particles is about 5 nm. The subsequent annealing at 1300 K results in the formation of crystalline YIG inside the opal voids. X-ray diffraction analysis has distinguished only the strongest YIG peak [420]. The filling factor of voids was 25-30% vol. The linear spectra of YIG-impregnated opals are measured for different angles of incidence. A clear maximum in the reflectance spectra corresponds to the photonic band gap in this photonic band gap material. The angular dependence of the reflectivity spectra reveals the features typical for opals, i.e. the spectral position of the peak red-shifts and its amplitude decreases when the angle of incidence increases. The tilt angle of the dependence corresponds to the diameter of SiO₂ spheres of the samples at the angle of incidence of 300. The second-harmonic generation (SHG) spectra of opal-YIG samples are measured. The spectral dependence of the SHG intensity is measured for the angle of incidence of 20 degrees in the spectral vicinity of photonic band gap (PBG) region. The SHG spectrum reveals a sharp peak in the SHG intensity at wavelength of 768 nm, which corresponds to the left PBG wing. Such behavior can be attributed to the fulfillment of the phase-matching conditions for the second harmonic generation. The phase-matching can be expected due to anomalous high dispersion of the PBG material in the vicinity of the PBG edge. For the studies of the magnetization-induced effects in SHG from opals infiltrated by Bi:YIG, the magnetic field of about 2 kOe is applied to the samples in the geometry of the transversal Kerr effect. In this case, odd with respect to the magnetization M changes in the SHG intensity are expected. As a measure of these changes, the SHG magnetic contrast is the ratio of the difference of the SHG intensities measured for the opposite directions of the magnetic field to the corresponding sum of the SHG intensities. The SHG magnetic contrast measured for opal-YIG samples attains the value of 0.04. This value is comparable with the typical values of magnetic contrast for YIG thin films of the similar composition and for the transversal magneto-optical Kerr effect, which is about 0.1.

Q8.5

Abstract Withdrawn

Q8.6

Textured Growth of Ferromagnetic Metal Sulfide Films using Single Source Precursor. Jia Mei Soon¹, Yong Lim Foo³, Jun Ding², Lai Yoong Goh¹ and Kian Ping Loh¹; ¹Department of Chemistry, National University of Singapore, Singapore, Singapore; ²Department of Material Science and Engineering, National University of Singapore, Singapore, Singapore; ³Institute of Materials Research and Engineering, Singapore, Singapore.

Transition metal sulfides of iron[1],[2],[3] and chromium[4] are interesting semiconducting materials which can exhibit ferromagnetism when the metal:sulfur atomic ratios are non-stoichiometric. When coupled with magnetic anisotropy character, they become potentially useful in the fields of magnetic semiconductors and field emission. Using the single source precursor iron diethyl-dithiocarbamate, we deposited highly textured nano-pillars of Fe_{0.975}S via chemical vapor deposition. Nanocrystals of Cr_{1.89}S₃ are deposited using a similar method with a chromium diethyl-dithioxanthate precursor. Both materials exhibit preferential orientation in the c-axis with respect to the substrate as investigated by texture analysis using high-resolution x-ray diffraction. The growth morphology of the nanomaterials are sensitive to the orientation of the substrate: When deposited on Si(100), the Fe_{0.975}S nanopillars are epitaxial i.e. the nanopillars exhibit in-plane registry as well as c-axis alignment, with a tilt of 14.5° off the normal. On Si(111), they exhibit fiber texture, with alignment in the c-axis. Similarly, Cr_{1.89}S₃ nanocrystals exhibit fiber texture when deposited on Si(100). Such assembly on the substrate occurs without the use of any template or catalyst. This unique morphology is due to the low lattice mismatch of less than 3% between the nanomaterials and substrate. In the case of Fe_{0.975}S, the NiAs-type crystal packing is also responsible for the unique crystal morphology. The well-defined shape anisotropy imparts magnetic anisotropy to the material, causing it to exhibit differential in-plane: out-of-plane magnetic anisotropy ratio of 4:1, with saturation magnetization of 12emu/g.

Q8.7

Spin Polarized Chalcogenide Thin Films Of CuCr₂Se₄. Joanna Bettenger¹, Rajesh V. Chopdekar^{2,1}, Marco Liberati³, Janell R. Neulinger⁴, Lisa Alldredge^{2,1}, Elke Arenholz⁵, William Butler⁶, Yves Idzerda³, Angelica Stacy⁴ and Yuri Suzuki¹; ¹Materials Science and Engineering, UC Berkeley, Berkeley, California; ²Applied Physics, Cornell University, Ithaca, New York; ³Department of Physics, Montana State University, Bozeman, Montana; ⁴Department of Chemistry, UC Berkeley, Berkeley, California; ⁵Advanced Light

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Tuscaloosa, Alabama.

Bulk forms of CuCr_2Se_4 have been known for many years to have a magnetization near $5\mu_B$ per formula unit at low temperatures and have a relatively high Curie temperature of 460K [1]. Recent electronic structure calculations indicate that this material is nearly half metallic, and the magnetic moment is primarily due to the high spin polarized Cr density of states balanced by small contributions from the Cu and Se sites with opposite magnetization. Therefore, given successful growth of CuCr_2Se_4 in magnetic thin film form, it would serve as an ideal electrode material for magnetic tunnel junctions. We have grown CuCr_2Se_4 films by pulsed laser deposition and varied deposition temperature, partial pressures, and single crystal substrates. Additionally, we have looked at the effect of post growth Se anneal on the film's properties, including magnetic and phase information. Depositions from room temperature to 650°C in a vacuum or selenium atmosphere exhibit magnetism on a variety of substrates, including MgO , MgAl_2O_4 , and LaF_3 . X-ray diffraction has indicated that we are growing films in the [111] direction, which can be grown epitaxially on (0001) LaF_3 with a 1.67% strain. Using a superconducting quantum interference device (SQUID) magnetometer, we have determined the magnetization value to be near the bulk value of $5\mu_B$ per formula unit. Atomic force microscopy reveals a topographically smooth surface with a RMS value of 0.24 nm, while magnetic force microscopy has been used to characterize the domain structure of the thin film. The Curie temperature is above 390K, the detection limit of our SQUID. X-ray magnetic circular dichroism and x-ray absorption spectroscopy have been performed on these films showing that high growth temperatures and vacuum background produce films that closely resemble those of the bulk CuCr_2Se_4 phase. [1] F.K. Lotgering. Solid State Commun. 2 (1964) 55.

Q8.8

Magnetoresistance and Transport-Magnetism correlations in Hole Doped Lanthanum Manganites Grown by Polymer Assisted Deposition. Menka Jain¹, P. Shukla², Y. Li¹, B. Maiorov¹, M. F. Hundley¹, M. E. Hawley¹, A. K. Burrell², T. M. McCleskey², L. Civale¹ and Q. Jia¹; ¹Materials Science Technology Division, Los Alamos National Laboratory, Los Alamos, New Mexico; ²Chemistry Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

The effect of colossal magnetoresistance (CMR) in hole-doped manganites ($\text{La}_{1-x}\text{M}_x\text{MnO}_{3+y}$, where $\text{M}=\text{Sr}$, Ca , and Ba) has attracted significant interest in the past decade. In a range of doping, $x\sim 0.2-0.4$, the ground state is ferromagnetic and the paramagnetic to ferromagnetic transition is accompanied by a sharp drop in resistivity (ρ), indicating that ρ is strongly influenced by the magnetic transition. An applied magnetic field (H) also suppresses ρ by aligning magnetic moments. In the present work, films of $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$ (LSMO) and $\text{La}_{0.67}\text{Ca}_{0.33}\text{MnO}_3$ (LCMO) were grown on single crystalline LaAlO_3 substrates by polymer assisted deposition developed recently at the Los Alamos National Laboratory. Significant improvement in the electrical properties of these films was observed with the annealing temperature. Both the resistivity and the large negative magnetoresistance peak near the ferromagnetic ordering temperature, with $\Delta\rho/\rho_0 = -50\%$ and -88% ($H=50\text{ kOe}$) in LSMO and LCMO films respectively. We have found a clear correlation between the microstructure, resistivity, and magnetization. The results of temperature and magnetic field dependent resistivity and magnetization measurements on the pure LCMO and LSMO films as well as in multilayered films will be presented in detail.

Q8.9

Abstract Withdrawn

Q8.10

Antiferromagnetic Structures in an fcc Lattice.

Felix Alexandrovich Kassan-Ogly and Boris Nikolaevich Filippov; Department of Theoretical and Mathematical Physics, Institute of Metal Physics, Ekaterinburg, Russian Federation.

A revised derivation scheme of possible antiferromagnetic structures in an fcc lattice with the nearest and next-nearest-neighbor interactions taken into account is proposed. Some new types of antiferromagnetic ordering have been revealed and it was shown that some antiferromagnetic structures considered in literature cannot exist at any values of the nearest and next-nearest-neighbor interactions. It was also shown that one and the same antiferromagnetic structure may correspond to different signs of the competitive nearest and next-nearest-neighbor interactions. A model of simultaneous magnetic and structural phase transitions of the first order is developed for antiferromagnets with a NaCl crystallographic structure and with a strong cubic magnetic anisotropy based on incorporation of magnetic modified 6-state and 8-state Potts models [1] and theoretical models of structural phase transitions in cubic

crystals [2]. It was shown that the high-temperature diffuse magnetic neutron scattering transforms into magnetic Bragg reflections below the Neel point and the neutron magnetic scattering pattern may correspond to different types of antiferromagnetic structures. A simple experimental test that consists in measuring the magnetization along the principal crystallographic axes below the Neel point is proposed to split this degeneracy. [1]. Kassan-Ogly F.A. Modified 6-State and 8-State Potts Models in Magnetic Field. Phase Transitions. 2000. V. 72. P. 223- 237. [2]. Kassan-Ogly F.A., Naish V.E., Sagaradze I.V. Diffuse Scattering and Structural Phase Transitions. Phase Transitions. 1994. V. 49. P. 89- 141.

Q8.11

The Magnetoresistant Property of the $\text{La}_{0.9}\text{Sr}_{0.1}\text{MnO}_3$ Thin Film Embedded with Pt nano-particles. Yen-Hua Chen¹ and Tai-Bor Wu²; ¹Department of Materials Science and Engineering, National Tsing-Hua University, Hsinchu, Taiwan; ²Department of Materials Science and Engineering, National Tsing-Hua University, Hsinchu, Hsinchu, Taiwan.

Very recently, enhanced magnetoresistance(MR) has been observed in some ferromagnetic-insulator(FM-I)-type composites, such as $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3\text{-CeO}_2$, $\text{La}_{0.67}\text{Ca}_{0.33}\text{MnO}_3\text{-SrTiO}_3$, $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3\text{-SiO}_2$, and so on. However, this combination commonly results in larger increase of resistivity and downshift of metal-insulator transition. If conducting metal nanoparticles(NP) are introduced into the manganite matrices to form ferromagnetic-metal type composites, enhancement of MR may be also expected due to the modification of grain-boundaries and/or magnetic scattering. In this paper, $\text{La}_{0.9}\text{Sr}_{0.1}\text{MnO}_3\text{-Pt(NP)-La}_{0.9}\text{Sr}_{0.1}\text{MnO}_3$ thin films were grown by R.F. magnetron sputtering on the $\text{SiO}_2(200\text{nm})/\text{Si}(100)$ substrate at room temperature, and then post-annealed at 600°C for 1 hr. The XRD pattern shows the crystalline peaks of LSMO and Pt. The relation of magnetization vs temperature reveals that the LSMO(20nm)-Pt-LSMO(20nm) has higher magnetization($\sim 100\text{ emu/cm}^3$) and Curie temperature(T_c) than those of LSMO(135nm)-Pt(NP)-LSMO(135nm). The phenomenon is so different from that of LSMO films having the same thickness, i.e. the LSMO thin films of 48nm has a magnetization of about 100 emu/cm^3 , and T_c of 200K, which are lower than those of LSMO thin film having 300nm thickness. The SEM investigation also reveals that the thicker film embedded with Pt nano-particle (total film thickness of 300nm) has cracks on the surface, which may be related to its lower T_c and poor magnetization. According to the study, we design the LSMO-Pt(NP)-LSMO composites with a total thickness of about 50nm embedded with Pt nano-particle to improve its resistivity and magnetic properties. The composites include LSMO-Pt(NP)-LSMO and LSMO-Pt(NP)-LSMO-Pt(NP)-LSMO. From the different distribution of Pt nano-particles, the electron transport path and mechanism will be studied.

Q8.12

Quasiferromagnetism in Semiconductors.

Thierry Alexandre Dubroca, Jonathan Hack and Rolf Hummel; MSE, university of florida, gainesville, Florida.

Until now, electron spin has been a relatively unexplored degree of freedom that offers to assist in the continuing progress of the micro-electronics industry. Spin-transport electronics (spintronics) is a newly evolving device technology that functions using electron spin, either alone or in conjunction with, electron charge. Our research focuses on understanding how certain semiconductors can result in a ferromagnetic-like hysteresis loop. Ferromagnetic hysteresis has been observed at room temperature in materials not consisting of elements commonly associated with ferromagnetism, such as, Co, Ni, Fe, or Mn-containing alloys. In particular, we report on magnetic hysteresis seen in silicon prepared by different techniques: ion implantation, neutron irradiation, and spark processing of silicon. Because the material investigated contains no ferromagnetic elements, we name them quasiferromagnetics. The paramagnetic defects present in these materials were additionally investigated using Electron Paramagnetic Resonance (EPR). We present our understanding of the relationship between the defects at the electronic level and the macroscopic magnetic hysteresis loop. We suggest that some defects are one of the factors responsible for the observed macroscopic magnetic hysteresis loop.

Q8.13

Ferromagnetic Properties of Clathrate Structured $\text{Eu}_8\text{Ga}_{16}\text{Ge}_{30}$ Thin Films Deposited by Pulsed Laser Deposition. Robert R Owings¹, Susan A. Schima¹, Brian C. Sales², David G. Mandrus² and David P. Pappas¹; ¹Quantum Electrical Metrology Division, NIST, Boulder, Colorado; ²Condensed Matter Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Bulk single crystal clathrate structured $\text{Eu}_8\text{Ga}_{16}\text{Ge}_{30}$ exhibits ferromagnetism with a Curie temperature of 35 K. In this structure, the Eu atoms can tunnel between sites in a 4-fold potential well. These materials have interesting thermo-caloric properties. However, it is difficult to integrate them into devices in the bulk form. Therefore, in this work we explore the feasibility of depositing these materials as thin films directly from a bulk single crystal target. The films were grown on sapphire substrates at 300 degrees celsius using pulsed laser deposition. The samples were then cooled slowly. SQUID magnetometry of the samples showed two ferromagnetic transitions, one at 8 K and one at 35 K, indicating a mixed phase with approximately equal parts of the two phases. The phase with the 35 K Curie temperature is identified as the clathrate phase. The phase with the 8 K transition temperature is a known phase of non-clathrate material. This demonstrates that it is possible to grow the clathrate phase in thin films using PLD. We will present Auger spectroscopy results from these films and the bulk reference samples to determine the stoichiometry. This will indicate the direction needed to stabilize pure clathrate phase films.

Q8.14

GaN Calcined with CuO in Air and N₂: Qualitative and Quantitative X-ray Diffraction Studies. Lori Kathleen Noice¹, Bjørn Seipel¹, Peter Moock¹, Amita Gupta^{1,2} and V. K. Rao²; ¹Physics, Portland State University, Portland, Oregon; ²Materials Science, Tmfy-MSE, The Royal Institute of Technology, Stockholm, Sweden.

Following the theoretical prediction that certain wide band-gap semiconductors may attain Curie temperatures well above room temperature when doped with transition metals, such as manganese, cobalt, iron, etc. (Dietl T. et al., 287 (2000) 1019), much attention has been given to zinc oxide and gallium nitride to achieve dilute magnetic semiconductors (DMS). Despite the fact that ferromagnetism above room temperature was achieved for copper-doped zinc oxide, the potential of copper doped gallium nitride as a DMS remains largely unexplored. Although a well known impurity of gallium nitride, the role of oxygen in the magnetic properties of the semiconductor is not well understood. In order to address the structural characterization of copper and oxygen doped gallium nitride, several samples of (wurtzite) GaN calcined with copper oxide (CuO) in air or nitrogen at 500 °C for 40 hours were analyzed with X-ray diffraction. Qualitative x-ray diffractometry show that in all the treated samples, gallium nitride and copper oxide were present. Gallium oxide hydrate (GaO₂H) was also detected in those samples calcined in air and in the untreated gallium nitride. The samples calcined in nitrogen did not contain GaO₂H, but did contain cuprite (Cu₂O), suggesting that a lack of oxygen (O₂) during sample preparation caused a reduction of the copper. In all the samples, including the untreated GaN, several unknown peaks in the diffractograms indicate that additional low concentration phases such as gallium oxide (Ga₂O₃) or gallium oxide hydroxide (GaO(OH)) may be present. Quantitative phase analyses and the determination of the GaN lattice constants were performed using the Rietveld method. For selected samples, the GaN lattice constants were also obtained by analytical extrapolation from high Bragg angles close to 90 degrees. Trends in the GaN lattice constants with initial CuO contents are explained by incorporation of both Cu and O into the GaN lattice.

Q8.15

Structural and Raman Spectroscopic Study of Fe doped SnO₂. Xavier Mathew¹, Concepcion Mejia-Garcia², Gerardo Contreras-Puente², Jason Hays³ and Alex Punnoose³; ¹UNAM, Temixco, Morelos, Mexico; ²ESFM-IPN, Mexico D.F., Mexico; ³Physics, Boise State University, Boise, Idaho.

The semiconductors can be made ferromagnetic by doping with transition metal ions. Ferromagnetic $\text{Sn}_{1-x}\text{Fe}_x\text{O}_2$ ($x = 0, 0.01, 0.03, 0.05, 0.1$) samples were prepared by wet chemical methods and the effect of Fe incorporation into the SnO₂ lattice was studied using X-ray diffraction, IR and Raman spectroscopy. The XRD studies showed that the doping affects the structure, and the lattice constants decrease as doping concentration increases, reaches a minimum and again increases. The doped samples are under compressive strain and the strain is maximum for the sample doped with 3 % (atomic percent) Fe. The grain size showed a 38% decrease when the doping concentration changed from 0 to 10%. Raman spectra showed clear evidences of the change in grain size and incorporation of Fe into the crystal lattice. The Raman bands observed in the 700 cm⁻¹ region is assigned to the vibrational local modes of the Fe³⁺ ions which are occupying the sites of Sn⁴⁺ ions. A clear correlation is found between the Fe Raman mode intensities and the ferromagnetic magnetization of $\text{Sn}_{1-x}\text{Fe}_x\text{O}_2$, suggesting that the ferromagnetic behavior results from Fe³⁺ ions incorporated in the host SnO₂ lattice.

Q8.16

Abstract Withdrawn

Q8.17

Ab Initio Study on The Magneto-Structural Properties of MnAs. Ivan Rungger and Stefano Sanvito; School of Physics, Trinity College Dublin, Dublin, Ireland.

The magnetic and structural properties of MnAs are studied by mapping ab initio total energies onto the Heisenberg model. This provides an explanation for both the first order phase transition at about 317 K and the second order phase transition at about 400 K. The stability of the different phases is found to depend mainly on the volume and on the amount of magnetic order, confirming previous experimental findings and phenomenological models. It is generally found that for large lattice constants the ferromagnetic state is favored, whereas for small lattice constants different antiferromagnetic states can be stabilized. In the ferromagnetic state the structure with minimal energy is always hexagonal, whereas it becomes orthorhombically distorted if there is an antiferromagnetic component in the hexagonal plane. For the paramagnetic state the stable cell is found to be orthorhombic up to a critical lattice constant of about 3.7 Å, above which it remains hexagonal. This leads to the second order structural phase transition between paramagnetic states at 400 K, where the lattice parameter increases above this critical value with rising temperature due to the thermal expansion. At 317 K the lattice constant for the paramagnetic state is smaller than this critical value and therefore it is stable in the orthorhombic structure. As MnAs becomes paramagnetic at this temperature the cell changes abruptly from hexagonal to orthorhombic, which corresponds to a first order phase transition. For the paramagnetic state an analytic approximation for the magnitude of the orthorhombic distortion as a function of the lattice constant is given. Within the mean field approximation the dependence of the Curie Temperature on the volume and on the orthorhombic distortion is calculated. For orthorhombically distorted cells the Curie temperature is much smaller than for hexagonal cells. This is mainly due to the fact that some of the exchange coupling constants in the hexagonal plane become negative for distorted cells. This is also the reason for the appearance of canted spin structures at low temperatures and high pressures, where the cell is orthorhombic. With these results a description of the susceptibility as function of temperature is given, where the temperature dependence enters via the dependence of the Curie Temperature on the lattice parameters.

Q8.18

Room-temperature Ferromagnetism of Cu-implanted GaN. Jong-Han Lee^{1,3}, Sangwon Shin^{2,3}, Jonghan Song³, Seung-Cheol Lee⁴, Jong-Hyeob Baek⁵, In-Hoon Choi¹ and Chungnam Whang²; ¹Materials Science and Engineering, Korea Univ., Seoul, South Korea; ²Physics and Applied Physics, Yonsei Univ., Seoul, South Korea; ³Advanced Analysis Center, Korea Institute of Science and Technology, Seoul, South Korea; ⁴Future Technology Research Division, Korea Institute of Science and Technology, Seoul, South Korea; ⁵LED Device Team, Korea Photonics Technology Institute, Gwangju, South Korea.

Recently, GaN and ZnO have been studied by doping with Mn, Cr, Ni, or Fe for Dilute magnetic semiconductors (DMS). In this work, Cu was used as a magnetic dopant. 1 MeV Cu²⁺ ion was implanted into GaN with dose of $1 \times 10^{17} \text{ cm}^{-2}$ at room temperature. After implantation, the samples were subsequently performed rapid thermal annealing from 700 °C to 900 °C for 5 min in nitrogen ambient at 1 torr. The magnetic properties were measured by a superconducting quantum interference device (SQUID) magnetometer. As-implanted sample shows a diamagnetism at room temperature. Both samples annealed at 700 °C and 800 °C show ferromagnetism. The saturation magnetization (Ms) of these sample are estimated to be 0.057 μ_B per Cu atom from M-H curve. But, sample annealed at 900 °C does not show ferromagnetism. It is possible that the Cu atoms segregate to form clusters in the annealing process at higher temperature than 800 °C. Metallic copper cluster is non-magnetic differently from other magnetic transition metals. The electronic and atomic structure were investigated by measuring of NEXFS, XES, XAS, XRD and the electric properties were studied by Hall measurement.

Q8.19

Room-temperature Ferromagnetism of 1 MeV Cu-implanted ZnO/Ga-doped ZnO and ZnO Films. Jong-Han Lee^{1,3}, Sangwon Shin^{2,3}, Jonghan Song³, Seung-Cheol Lee⁴, Won-Kook Choi⁵, In-Hoon Choi¹ and Chungnam Whang²; ¹Materials Science and Engineering, Korea Univ., Seoul, South Korea; ²Physics and Applied Physics, Yonsei Univ., Seoul, South Korea; ³Advanced Analysis Center, Korea Institute of Science and Technology, Seoul, South Korea; ⁴Future Technology Research Division, Korea Institute of Science and Technology, Seoul, South Korea; ⁵Thin Films Materials

Center, Korea Institute of Science and Technology, Seoul, South Korea.

Dilute magnetic semiconductors (DMS) have received considerable attention because of the possibility of incorporating magnetic degrees of freedom into semiconductor devices. Typically, ZnO system has been doped with Mn, Co, Ni, Cr, V or Fe for DMS. Copper as a magnetic dopant in ZnO has been predicted to be ferromagnetic and some was reported magnetic behavior. We report the ferromagnetism of Cu-doped ZnO system. Firstly, ZnO(5000)/Ga-ZnO(5000) (ZGO) and ZnO(9500) were grown on sapphire by plasma assisted molecular beam epitaxy. 1 MeV Cu²⁺ ion with dose of 1X10¹⁷ cm⁻² was implanted into ZGO and ZnO at room temperature. In ZGO case, the implanted Cu atoms distributed in Ga-doped ZnO and ZnO layer. The magnetic properties were measured by a superconducting quantum interference device (SQUID) magnetometer at room temperature. As-implanted ZnO does not show a ferromagnetism. But as-implanted ZGO show ferromagnetism with the saturation magnetization of 0.083 μ_B per Cu atom from M-H curve. These samples were subsequently performed rapid thermal annealing at 800 °C for 5 min in oxygen ambient at 1 torr. After annealing both ZnO and ZGO do not show ferromagnetism. During annealing process Ga-doped ZnO layer affects implanted-copper. The electronic and atomic structure were investigated by measuring of NEXFS, XES, XAS, XRD and the electric properties were studied by Hall measurement.

Q8.20

Photoinduced Phase-separation in Bi_{0.4}Ca_{0.6}MnO₃ Thin Films. Vera N. Smolyaninova, Robert Kennedy, Elena Talanova, Luis Aldaco, Rajeswari M. Kolagani and Mason Overby; Dept. of Physics, Astronomy and Geosciences, Towson University, Towson, Maryland.

Doped rare-earth manganese oxides (manganites) exhibit a wide variety of physical phenomena due to complex interplay of electronic, magnetic, orbital, and structural degrees of freedom. One of the most intriguing properties of manganites is coexistence of two (or several) distinct electronic phases. A photoinduced insulator to conductor transition in charge-ordered (CO) manganites is especially interesting from the point of view of creating photonic devices [1]. We have observed a photoinduced sub-micron phase coexistence of CO insulating phase and conducting phase via optical contrast in Near-field Scanning Optical Microscope (NSOM) images. Such phase coexistence is possible because of the presence of two local energy minima corresponding to CO insulating and charge-disordered conducting phases in the energy landscape [2]. To better understand the physics of phase coexistence in manganites we studied the dynamics of photoinduced conductivity changes. The temperature dependence of this process will be presented. The energy barrier separating the CO insulating and conducting states will be discussed. This work is supported by the NSF under grants DMR-0348939 and DMR-04221141. [1] V. N. Smolyaninova et al., Appl. Phys. Lett. 86, 071922 (2005). [2] K. H. Ahn et al., Nature 428, 401 (2004).

Q8.21

Room-Temperature Ferromagnetism of Co-Doped TiO₂ Thin Films Grown by Plasma-Enhanced Metal-Organic Chemical Vapor Deposition. Eui-Tae Kim¹, Nak-Jin Seong¹, Soon-Gil Yoon¹ and Myung-Hwa Jung²; ¹Dept. of Materials Engineering, Chungnam National University, Daejeon, South Korea; ²National Fusion R&D Center, Korea Basic Science Institute, Daejeon, South Korea.

Diluted magnetic semiconductors (DMS) have attracted considerable research interests because of their potential spintronic applications such as spin transistors, nonvolatile storage, logic devices, etc. Realizing a room-temperature ferromagnetism of DMS is central to exploiting their full potential. Recently, Co-doped TiO₂ anatase, grown by pulsed laser ablation, has been demonstrated to be ferromagnetic and semiconducting for doping levels up to around 8 at.%, and temperatures of up to 400K [1]. Such Co-doped anatase TiO₂ DMS thin films were prepared by oxygen plasma-assisted molecular beam epitaxy and sol-gel process as well. For increase of integration levels in Si process, a demand for thin film fabrication methods with precise composition control, conformal step-coverage, good uniformity, and high throughput is increasing. The chemical vapor deposition (CVD) technique is well-known as the best approach to fulfill these requirements. In this presentation, we report the systematic study of the microstructure and the magnetic characteristics of transition metal-doped TiO₂ DMS thin films grown by metal-organic CVD (MOCVD) and plasma-enhanced MOCVD (PEMOCVD). Co-doped TiO₂ DMS thin films are prepared onto SiO₂/Si and R-Al₂O₃ (1102) substrates using (C₁₁H₁₉O₂)₂(C₃H₇O)₂Ti and Co(C₁₁H₁₉O₂)₃ as the metal-organic sources. Using MOCVD, Ti_{1-x}CoO₂ thin films deposited on SiO₂/Si at 400 °C showed a polycrystalline anatase phase while thin films prepared at 450 °C were a rutile structure, irrespective of Co doping levels. The microstructure and magnetic characteristic of Ti_{1-x}CoO₂ DMS thin films are strongly depends on Co doping levels. After

annealing at 700 °C in vacuum ambient, Ti_{1-x}CoO₂ thin films with a composition less than x=0.05 had as uniform and smooth surface morphology as as-deposited ones. Samples having a composition above x=0.05, however, showed a severe Co-rich precipitation on the surface. We think that the Co solid solubility in Ti_{1-x}CoO₂ thin films prepared by MOCVD is approximately 5 at.%. The magnetization hysteresis loops were observed in the range of x=0.03 to 0.12, indicating anatase Ti_{1-x}CoO₂ thin films are ferromagnetic even at room temperature. As the Co doping level increased, the saturation magnetization abruptly increased and the coercive field markedly decreased. Such a magnetic behavior can be explained by a microstructural change related to Co-rich precipitation and agglomeration. Above x=0.05, the Co-rich clusters having a soft magnetic property increases the saturation magnetic field and decreases the coercive field. We will further discuss the characteristics of Ti_{1-x}CoO₂ DMS thin films having high Co doping levels, meanwhile suppressed Co-rich precipitation by deposition at a low temperature using PEMOCVD. [1] Y. Matsumoto, M. Murakami, T. Shono, T. Hasegawa, T. Fukumura, M. Kawasaki, P. Ahmet, T. Chikyw, S.-Y. Koshihara, and H. Koninuma, Science 291, 854 (2001).

Q8.22

Magnetic Rare Earth (Gd) implanted Tetrahedral Amorphous Carbon (ta-C). Li Zeng^{1,2}, Erik Helgren¹, Frances Hellman¹ and Carsten Ronning³; ¹Physics, UC, Berkeley, Berkeley, California; ²Materials Science Program, UC, San Diego, La Jolla, California; ³Institute of Physics, Georg-August-Universität Göttingen, Göttingen, Germany.

Tetrahedral amorphous carbon (ta-C) thin films were prepared by Mass Selected Ion Beam Deposition (MSIB) using 100eV carbon ions at room temperature (RT). Amorphous carbon (a-C) films prepared under such conditions exhibit high sp³ fraction up to 80% and have diamond-like properties. They are under extensive study as a potential wide band gap semiconductor. ¹⁵⁵Gd, a rare earth magnetic dopant, was implanted with varying energy and fluence at RT into these ta-C films. The purpose is to study the magnetic interactions between the magnetic centers as well as the correlation between the moments and the carriers (magneto-transport properties) in this wide band gap amorphous semiconductor matrix. Previous studies on Gd doped amorphous silicon (a-Si) have shown remarkable physics for compositions near the three-dimensional metal-insulator (MI) transition: many orders of magnitude negative magnetoresistance (MR) at low temperatures, and a high onset temperature (T*) where the effect of magnetic dopants turns on. Both MR and T* are significantly reduced when doping Gd into a-Ge and sp² rich a-C(H), which have narrow band gap and consequently larger dielectric constant. We believe this is due to the larger electron screening effect, thus larger MR and T* are expected for Gd doped in a true ta-C matrix. The influences of the Gd ion implantation (dose and energy) on the ta-C matrix are studied by Raman spectroscopy. Chemical and structural properties are studied by RBS and TEM. The temperature and magnetic field dependence of electrical conductivity and magnetic properties as a function of Gd concentration and materials structure have been determined. Results and comparison to previous work will be discussed and presented. Thanks for the NSF for support.

Q8.23

Atomic Scale Characterization of Co and Nb-doped TiO₂/LaAlO₃ Interface. Lianfeng Fu¹, Nigel D. Browning^{1,2}, Shixiong Zhang³, Darshan C. Kundaliya³, Satish B. Ogale³ and T. Venkatesan³; ¹Chemical Engineering and materials science, University of California at Davis, Davis, California; ²National Center for Electron Microscopy, Lawrence Berkeley National Laboratory, Berkeley, California; ³Center for Superconductivity Research, University of Maryland, College Park, College Park, Maryland.

Diluted magnetic semiconductor (DMS) materials, such as Co-doped TiO₂ films, have aroused much attention due to their potential application in the rapidly developing area of spintronics. However, the fundamental issues in the DMS materials, such as the origin and the nature of FM, are still in controversy. Beside this, the magnetic properties of Co-doped TiO₂ films are found to depend critically on the Co distribution, which is also strongly dependent on the growth process. In this regard, the structural qualities of the diluted magnetic semiconductors play an important role in maintaining the spin character of the electron and its magnetic properties in the devices. To fully develop the DMS materials for spintronics applications, it is therefore necessary to characterize and understand the properties of the DMS thin films as a function of the growth conditions. Thin films of anatase Ti_{1-x}CoxNbyO_{2-δ} (x= 0.03, y=0.0, 0.01) studied in this work were grown on (001) LaAlO₃ (LAO) single crystalline substrates by a pulsed laser deposition method with an excimer laser at 875 degrees at an oxygen partial pressures of 1x10⁻⁵ torr. After the growth, the cross-section of thin film samples was characterized using high spatial resolution scanning transmission electron microscopy

(STEM) Z-contrast imaging and electron energy loss spectroscopy (EELS) on a 200kV Schottky field-emission gun (FEG) FEI Tecnai F20. STEM Z-contrast imaging in the pure Co doped TiO₂ thin film under this growth condition revealed the formation of nanoclusters mostly at the heterointerface. EELS measurements revealed that these clusters were Co-rich titanium oxide and excluded that they were metallic Co with the valence state measurements. However, in the Co and Nb co-doped TiO₂ thin film, the interface was observed to smooth and epitaxial with no clustering. The same EELS measurements across the thin film showed the formation of a uniform Co-rich Ti_{1-x}Co_xNb_yO_{2-δ} surface phase enrichment without clusters. The experimental results showed that cobalt distribution in TiO₂ thin films not co-doped with Nb was sensitive to the oxygen pressure. The Nb doping effect on the ferromagnetism and its chemical role on the microstructure of TiO₂ thin films will be discussed here. This research was performed at the National Center for Electron Microscopy, LBNL supported by the U.S. DOE under Contract No. DE-AC02-05CH11231. The financial support is provided by NSF on Grant No. DMR-0335364 and NSF-MRSEC on grant No. DMR-00-80008.

Q8.24

Synthesis and Characterization of Mixed Iron-Oxide Nanoparticles/Poly(styrene-co-carboxyalkylmaleimide) Composites. Selene Sepulveda-Guzman¹, Odilia Perez-Camacho¹, Oliverio Rodriguez-Fernandez¹, Amelia Olivas-Sarabia² and Roberto Escudero³; ¹Centro de Investigacion en Quimica Aplicada, Saltillo, Coahuila, Mexico; ²Centro de Ciencias de la Materia Condensada (UNAM), Ensenada, Baja California, Mexico; ³Instituto de Investigacion en Materiales (UNAM), Mexico, DF, Mexico.

Hybrid materials composed of polymer and iron oxide nanoparticles are interesting because they combine organic functionality and processability with magnetic properties. These materials are used in novel separation systems and magnetic information storage technologies. In this work, maghemite (γ -Fe₂O₃) and goethite (α -FeOOH) nanoparticles, were deposited within a styrene/carboxyalkylmaleimide copolymer matrix. Iron oxide deposition was done by repeated treatments with ferrous chloride followed by alkaline oxidation. X-ray diffraction (XRD) analysis was used to identify the inorganic phase and shown the formation of γ -Fe₂O₃ and α -FeOOH after each deposition cycle. The chemical composition of the composites was studied by X-ray photoelectron and Fourier transform infrared spectroscopy. Alkaline oxidation of the template results in the formation of sodium carboxylate groups, that promoted the adsorption of ferrous ion by the matrix. Iron oxide deposition showed an autocatalytic pathway leading to an exponential increment with number of deposition cycles. Morphology and particle size distribution were determined by high resolution transmission electron microscopy. These results are in agreement with particle size determination by means of wide angle X-ray diffraction, using the Scherrer equation. Mean particle size for γ -Fe₂O₃ phase was of 14 nm whereas for α -FeOOH phase was of 24 nm. The magnetic properties dependence on the number of deposition cycles was investigated by magnetometry. In addition, zero-field-cooled and field-cooled analysis were used to investigate the magnetic behavior of the synthesized composite. The poly(styrene-carboxyalkylmaleimide)/ γ -Fe₂O₃/ α -FeOOH/composites showed a soft ferrimagnetic behavior, with a saturation magnetization of 8 emu/g, a coercivity of 50 Oe, and a blocking temperature of 26 K.

Q8.25

An ab initio Study of the Giant Magnetocaloric Effect in MnAs. HyeJung Kim¹, Y.-C. Chang^{2,1} and S. Chaieb³; ¹Department of Physics, University of Illinois at Urbana-Champaign, Urbana, Illinois; ²Research Center for Applied Science, Academia Sinica, Taipei, Taiwan; ³Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois.

MnAs is one of the materials which show a giant magnetocaloric effect. Electronic and magnetic properties of MnAs in NiAs structure and hypothetical zinc-blende structure are studied using a full potential linear augmented-Slater-type-orbital (LASTO) method¹⁻³ within the local spin density approximation. Total energies and magnetic moments as a function of volume as well as band structures are in agreement with previous calculations employing different methods such as full potential linearized augmented plane wave method and a plane-wave pseudopotential implementation. Exchange coupling parameters are determined with a frozen magnon approach⁴. Using the exchange coupling parameters obtained, a mean-field theory is applied to calculate the quantities of interest such as the magnetic entropy and free energy as a function of temperature and the critical temperature⁵, to evaluate the giant magnetocaloric effect in MnAs. <u></u> ¹J.W.Davenport, Phys. Rev. B 29, 2896(1994) ²J.W.Davenport, M.Weinert, and R.E.Watson, Phys. Rev. B 32, 4876(1994) ³J.W.Davenport, R.E.Watson, and M.Weinert, Phys. Rev.

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Q8.26

Deposition of Magnetic Materials on Organic Self Assembled Monolayers. S. N. Ahmad¹, S. G. Rao^{2,1} and S. A. Shaheen¹; ¹Physics & Center for Materials Research and Technology, and Center for nanomagnetism and Biotechnology, Florida State University, Tallahassee, Florida; ²Physics, Western Illinois University, Macomb, Illinois.

The concept of exploiting soft materials for memory applications poses a great challenge and recent developments in organic self assembled monolayers may facilitate studying interactions of soft matter with conventional memory (magnetic) materials. We report for the first time the effect of depositing a magnetic material (permalloy) on the organic self assembled monolayers as well as on patterned self assembled monolayers surfaces. The interface between the organic monolayer and permalloy may be fundamentally different from the conventional metallic interfaces, because a chemical reaction may be occurring at the interface here. When permalloy is deposited on the patterned surfaces having different functional groups of self assembled monolayers, it is observed that the deposition is very uniform and smooth in the regions where the self assembled monolayer is polar in nature, and it is non-uniform and cluster like in the regions where the self assembled monolayer is non-polar in nature. Consequently, depending upon the functional group of the self assembled monolayer, magnetic properties are affected. We compare the magnetic properties of permalloy films deposited on self assembled monolayers with a variety of functional groups.

Q8.27

Mn Doped Ge in Spintronics. Sriram K Dixit¹, SVS Nageswara Rao Sunkaranam², An Ping Li³, Matthew Chisholm³, Hanno H Weitering^{4,3} and Leonard C Feldman^{2,1,3}; ¹Interdisciplinary Materials Science, Vanderbilt University, Nashville, Tennessee; ²Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee; ³Condensed Matter Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee; ⁴Department of Physics and Astronomy, The University of Tennessee, Knoxville, Tennessee.

Devices that rely on electron spin form the foundation for spin-based electronics, also known as magnetoelectronics or spintronics. Mn doped Ge is one of the materials systems currently under study for this technology. A group IV based system, such as Ge, may be silicon compatible and hence meld smoothly with current technology. We present a combined ion beam/electron microscopy/magnetotransport study of the Ge(Mn) materials system in ferromagnetic Mn_xGe_{1-x} epitaxial films. The materials structure supports the model associated with the unusual magnetotransport properties. Films were grown by Molecular Beam Epitaxy (MBE) at temperatures of 50-110° C at a growth rate of 2-4 Å / min with a substrate temperature of 250° C with varying Mn concentrations of up to 9%. Nanoscale Mn clusters are revealed using transmission electron microscopy, electron energy loss spectroscopy, and channeling Rutherford backscattering spectroscopy. About 20% of total Mn is in the substitutional site of Ge as measured by channeling along the <100> and the <110> crystalline directions. The channeling and the TEM/EELS data are in strong agreement in the concentration values for the substitutional and the interstitial Mn in the Mn_xGe_{1-x} amorphous clusters. The combination of clusters and the substitutional dopants leads to a model of magnetotransport described by extended hole states (substitutional component), which mediate the cluster driven magnetism.

Q8.28

Magnetism in InP:Mn Quantum Dots. Yudhisthira Sahoo¹, Jerome B Keister¹, Pankaj Poddar², Sanyadanam Srinath², Srikanth Hariharan² and Paras N Prasad¹; ¹Chemistry, Institute for Lasers, Photonics and Biophotonics, SUNY at Buffalo, Buffalo, New York; ²Physics, Materials Physics Laboratory, University of South Florida, Tampa, New York.

Quantum Dots of diluted magnetic semiconductor (DMS) are zero dimensional counterparts of the two dimensional quantum well spintronics structures. We present the preparation of InP:Mn quantum dots from custom made precursors by hot colloidal nanotechnology. These quantum dots are uniform spheres with 3nm diameters, crystalline, photoluminescent and magnetic. The crystallographic and optical properties are similar to undoped InP nanocrystallites signifying that the lattice and photoluminescence characteristics of the host InP are preserved. Structural characterization and analysis confirm there are no segregated binary MnP or MnO phases. We observe robust onset of ferromagnetic order in magnetization

measurements at around 25K with blocked state behavior below 15 K, a trend characteristic of magnetic nanocrystallites. The system shows strong frequency dependence of the susceptibility, similar to the behavior observed for spin glasses. Reversible transverse susceptibility experiments done using a resonant radio-frequency (RF) method reveal a strong temperature-dependent effective anisotropy.

Q8.29

Magnetic Properties of Microcrystalline Si Thin films and Nickel Silicide Nanowires. Joondong Kim¹, Seongjin Jang²,

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The silicides, such as NiSi₂ and CoSi₂, have been attractive materials to crystallize Si and grow an epitaxial Si film with a small lattice mismatch to Si of 0.46% and 1.23%, respectively. The silicides are popularly used in interconnection as well as device applications such as a transistor with Si/NiSi₂ or Si/CoSi₂ structures. Additionally silicide nanowires are promising entities in nanoscale technology due to the small scale contact area and low resistivity. The hybrid structure of the magnetic/semiconductor materials have a potential for combining semiconducting and magnetic behavior in one system. Although much research has been performed on silicide materials, very few studies have been reported for the magnetic properties of the silicides. We herein report the growth mechanisms of microsize polycrystalline (mc)-Si and Ni silicide nanowires (NWs) based on silicide formation and the magnetic behavior. A 200 nm SiO₂ layer was first deposited by plasma enhanced chemical vapor deposition acting as a buffer layer against metal diffusion into the Si substrate. Ni was thermally evaporated to be a catalyst metal layer for both poly-Si and NW growth. Si was sputtered from a Si target by a dc magnetron. A higher power, up to 200W, was applied for mc-Si growth at 600 °C. Compared to the mc-Si growth procedures, a lower sputtering power (5 - 30W) was used in NW growth at a lower temperature of 575 °C. The surface morphological changes and cross sectional observation were investigated by a field emission electron microscope. The mc-Si was grown in columnar fashion to a 2.5 μm thickness. The grain size ranged from 0.5 to 1 μm in diameter. NWs were grown above 3 μm in length with 30 - 80 nm in diameter. X-ray diffraction was performed to analyze the mechanism of metal silicide formation of the mc-Si film and NW growth. In the mc-Si film, NiSi₂ was formed as seeds of poly-Si growth with little lattice mismatch. The main peaks exhibited were Si (111), (220), and (311) at 28.7°, 47.6°, and 56.2°, respectively. The Si peaks are close to NiSi₂ peaks, which indicate good epitaxial crystalline Si. The minor peaks of Ni rich phases (Ni₃Si₂ and Ni₃Si) were also found. Otherwise, the NW grown sample showed the NiSi peaks (2 1 1), (1 2 1), and (0 0 4), Ni₃Si₂ (2 2 1), and Ni₃Si (2 2 0). The magnetic properties of the mc-Si and NW grown samples were carried out at room temperature using a VSM magnetometer in the applied magnetic field ranging up to 5000 Oe. The NiSi₂ induced mc-Si sample showed a saturated magnetization of 50.6 emu/cm³. The magnetization of the nanowire grown sample was estimated to 77 emu/cm³. The difference may originate from the silicide formation. This heterostructure of magnetic silicide/mc-Si has a potential for spintronics combined semiconductors. We will present the possibility of growing magnetic/semiconductor structures and discuss the magnetic properties of Ni induced mc-Si and NWs.

Q8.30

Abstract Withdrawn